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Hammond, Theodore E.
Hamner, Edward C., Jr.
Haydock, Robert S.
Henderson, Lawrence L.
Hiatt, Frank M.
Hill, Sherwin A.
Howard, David C.
Hsin, Chee S.
Hyde John H.
Hyde, John S.

Ireland, Robert L.
Irving, Washington.

Jeffrey, Alexander H.
Jones, Frank B.
Joy, Richard P.
Joys, Carl C.
Jupp, Alfred J.

Katzenstein, Jacob.
Keilholtz, P. O.
Keller, Otto B.
Kellogg, James W.
Kempff, Louis.

Lam, Von-fong.
Larkin, Thomas J.
Lassen, Victor C.
Lauman, P. G.
Leaveston, A. Clifton.
Leslie, S. Inglis.
Lincoln, Preston S.
Livingstone, William.
Longstreth, Charles.
Lord, Frederick K.
Lundin, Andreas P.

McGregor, John A.
McGuire, James C.
McIntyre, Edward.
McLeod, S. Victor.
McQuesten, Fred.
MacDonald, Charles H.
Macy, William D.
Marvin, Winthrop L.
Mason, Lewis A.
Masten, Frank S.
Mathewson, Thomas S.
Meek, John E.
Meek, Wentworth W.
Miller, Jacob W.
Miller, Thomas I.
Mishtowt, Illarion V.
Mitchell, John.
Morch, Hans R.
Morgan, Edwin D.
Morton, James S.
Musham, Harry A.

Newberry, Truman H.
Niblack, Albert P.
Nickerson, H. O.
Niven, David W.
Norton, Edmund R.

Olcott, Alfred V. S.
Osborn, Frank H.

Paine, Cecil E.
Peck, Claude J.
Phillips, William H.
Pleasants, William H.
Powelson, Wilfred V. N.

Raven, Anton A.
Raymond, Harry H.
Raymond, James R.
Rea, Samuel.
Reuterdahl, Henry.
Richardson, Eugene M.
Richardson, Holden C.
Robins, William B.
Rodgers, William L.
Rogers, Walter H.
Rossell, Henry E.
Ruprecht, Fritz K.
Russel, John R.
Russell, John E.

Sabin, Alvah H.
Sanford, Leigh R.
Satterlee, Herbert L.
Schafer, Carl A.
Scholz, Robert C.
Sebree, Uriel.
Shaw, Howard L.
Shaw, William.
Sheerin, Robert A.
Simpson, Robert C.
Smith, Alfred G.
Smith, Bryant R.
Smith, Robert A. C.
Smith, William A. F.
Speakman, Edward M.
Sprague, Frank J.

Tams, J. Frederic.
Taylor, Stevenson Peirce.
Thearle, Philip H.
Thomas, Joseph D.
Thorp, Harry W.
Toch, Henry M.
Todt, Edward G.
Tomlinson, Joseph D.
Truscott, Starr.

Van Duzer, Louis S.
Veit, Richard C.

Wales, Charles M.
Walker, Herbert B.
Waycott, Albert K.
Welles, Roger.
White, Elisha J.
White, George A.
Whiton, Chauncey G.
Wilkinson, Horace S.
Williams, William E.
Winslow, John.
Wood, Henry A. Wise.
Wright, William L.

Zeigler, Samuel J., Jr.

JUNIORS

Adams, Henry C., Jr.
Allen, Walter D.
Altamiranos, Felipe.

Baier, Louis A.
Bibber, Leon C.

Colby, Haldwell S.
Colley, G. A.

De Ganahl, Frank.

Goldstein, Martin L.
Gross, Charles F.
Hanford, Edgar F.
Hooper, Parr.

Jennison, Clay L.

Laing, George, Jr.
Lingan, Prentiss.

Newton, G. A.
Nordstrom, Carl J.

Peterson, Carl E.

Rakestraw, Linn M.
Roundy, Caryl H.
Roundy, Henry J.

Saunders, Keith L.
Schmidt, John D.
Smith, G. Brick.
Smith, Ralph M.
Sperry, Edward G.

Todd, J. Herbert.
Track, Frank A.

Wilsberg, Carl E.

Yuan, Tsin.

ARTICLES OF INCORPORATION

THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS

State of New York,
City and County of New York.

We, the subscribers, Wm. H. Webb, Chas. H. Cramp, George E. Weed, H. Taylor Gause, William T. Sampson, Horace See, Frank L. Fernald, Francis T. Bowles, Washington L. Capps, Edwin D. Morgan, George W. Quintard, Harrington Putnam and Jacob W. Miller, being persons of full age and citizens of the United States, of whom a majority—namely, William H. Webb, George E. Weed, Horace See, Edwin D. Morgan, George W. Quintard, Harrington Putnam, Frank L. Fernald, and Jacob W. Miller are citizens of and residents of and within this State, desiring to associate ourselves for scientific purposes under, and pursuant to, an Act of the State of New York providing for the incorporation of benevolent, charitable, scientific, and missionary societies, passed April 12, 1848, and the several acts amending or supplementing the same, do hereby, in accordance with the requirements thereof, certify as follows:—

First. The name of title by which the Society shall be known in law is The Society of Naval Architects and Marine Engineers.

Second. The particular business and objects of such Society are the promotion of practical and scientific knowledge in the arts of shipbuilding and marine engineering and the allied professions, and in furtherance of this object, to hold meetings for social intercourse among its members, and the reading and discussion of professional papers, and to circulate by means of publication the knowledge thus obtained.

Third. The number of directors, trustees, or managers to manage the Society shall be seven, and shall consist of a President, a Secretary, and five Members of Council.

Fourth. The names of the trustees, directors, or managers of the Society for the first year of its existence are:—President, Clement A. Griscom; Secretary, Washington L. Capps; Members of Council, Francis T. Bowles, H. Taylor Gause, Chas. H. Loring, Lewis Nixon, Harrington Putnam.

Fifth. The business of the Society is to be conducted, and its place of business and principal office is to be located, in the City and County of New York.

In Witness Whereof we have made, signed and acknowledged this Certificate, this 28th day of April, 1893.

WILLIAM H. WEBB.
CHAS. H. CRAMP.
H. T. GAUSE.
GEORGE E. WEED.
W. T. SAMPSON.
HORACE SEE.
F. L. FERNALD.
FRANCIS T. BOWLES.
W. L. CAPPS.
E. D. MORGAN.
GEORGE W. QUINTARD.
HARRINGTON PUTNAM.
J. W. MILLER.

City and County of New York, *ss:*

On this 28th day of April, 1893, before me personally appeared William H. Webb, Charles H. Cramp, H. Taylor Gause, George E. Weed, William T. Sampson, Horace See, Frank L. Fernald, Francis T. Bowles, Washington L. Capps, and Edwin D. Morgan, to me known and known to me to be the persons described in and who executed the foregoing certificate, and severally acknowledged to me that they executed the same.

James Forrester,
Notary Public, Kings Co., Cert. N. Y. Co.

City and County of New York, *ss:*

On this 1st day of May, 1893, before me personally appeared George W. Quintard and Harrington Putnam, to me known and known to me to be the individuals described in and who executed the foregoing certificate, and they severally acknowledged to me that they executed the same.

James Forrester,
Notary Public, Kings Co., Cert. N. Y. Co.

City and County of New York, *ss:*

On this 9th day of May, 1893, before me personally appeared Jacob W. Miller, to me known and known to me to be one of the individuals described in and who executed the foregoing certificate, and he duly acknowledged to me that he executed the same.

James Forrester,
Notary Public, Kings Co., Cert. N. Y. Co.

(Endorsed.)

Upon reading the within Certificate for the Incorporation of the Society of Naval Architects and Marine Engineers, I hereby approve and consent to the incorporation thereof and the within Certificate and filing thereof, and direct that the same be filed in the office of the Clerk of the City and County of New York.

Dated New York, May 10, 1893.

Edwd. Patterson,
Justice of the Supreme Court in the State of New York,
in and for the City and County of New York.

CONSTITUTION AND BY-LAWS OF THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS

Article I.

Name and Object.

1. The name of the Association shall be "The Society of Naval Architects and Marine Engineers."

2. Its object shall be the promotion of the art of shipbuilding, commercial and naval.

3. In furtherance of this object, annual meetings shall be held for the reading and discussion of appropriate papers and interchange of professional ideas, thus making it possible to combine the results of experience and research on the part of shipbuilders, marine engineers, naval officers, yachtsmen, and those skilled in producing the material from which ships are built and equipped.

Article II.

Membership.

1. The Society shall consist of Members, Associates, Juniors, Honorary Members and Honorary Associates.

2. *Members.*—(1) The class of Members shall consist exclusively of Naval Architects, Marine and Mechanical Engineers, including Professors of Naval Architecture or Mechanical Engineering in colleges of established reputation.

(2) A candidate for this class must not be less than twenty-eight years of age and comply with the following regulations: He shall submit to the Council a statement showing that he has been engaged in the practice of his profession, in a responsible capacity, for at least five years, and setting forth the grounds upon which he bases his claim to membership. This statement shall be signed by three Members, who shall certify to their personal knowledge of the candidate and approval of his statement.

(3) In the case of persons not American citizens, the signatures of three Members shall be required in confirmation of their personal knowledge of the candidate's scientific attainments.

(4) If three-fourths of the members of the Council present are in favor of the admission of the candidate his name shall be submitted to the Members of the Society at the next meeting; the voting to be by ballot, should a ballot be demanded.

3. *Associates.*—(1) The class of Associates shall consist of persons who, by profession, occupation, or scientific attainments, are qualified to discuss the qualities of a ship.

(2) Candidates for this class shall submit to the Council a written statement of their qualifications for membership; this shall be signed by two Members or Associates who shall certify to their personal knowledge of the candidate and approval of his statement. If considered by three-fourths of the Council present duly qualified for associate membership their

names shall be submitted to the Society at the next meeting, to be voted upon by the Members and Associates; the voting to be by ballot, should a ballot be demanded.

4. The proportion of favorable votes for deciding the election of Members and Associates shall be at least four-fifths of the number recorded.

5. *Juniors.*—(1) The class of Juniors shall consist of graduates of technical schools of established reputation, or persons who have had not less than two years' practical experience in marine engine works or shipyards.

(2) Candidates must be at least eighteen years of age and certify their intention to continue in the profession and become naval architects or marine engineers.

(3) Juniors shall be eligible for transfer to the class of Members or Associates after fulfilling the necessary conditions; when they are twenty-eight years of age they shall be offered the option of being transferred to the class of Members or Associates in conformity with their qualifications; but if they do not accept such offer or do not qualify, they shall be dropped from the rolls of the Society.

(4) The admission of Juniors shall be by a favorable vote of three-fourths of the members of the Council present.

(5) Juniors shall have no voice in the government of the Society or admission of members.

6. *Honorary Members and Honorary Associates.*—The Council may elect Honorary Members and Honorary Associates, the total number not to exceed twenty-five. They shall be persons of acknowledged eminence in their profession upon whom the Council may see fit to confer an honorary distinction.

7. *Benefactors and Permanent Members.*—The Council may establish a list of Benefactors. It may also elect as Permanent Members of the Society such Members or Associate Members as shall, in the opinion of the Council, by reason of notably liberal contributions to the Society, merit special recognition. Permanent Members shall, from the date of their election, be relieved from annual dues, and shall have the right, subject to the approval of Council, to designate by will or otherwise, their successors. The conditions to be met before placing any name on the list of Benefactors and the regulations governing the election of Permanent Members shall be prescribed by the Council.

Article III.

Dues, Suspension and Expulsion of Members.

1. The entrance fees, payable on admission to the Society, shall be as follows:—

Members and Associates, ten dollars; Juniors, five dollars; Honorary Members and Honorary Associates, no fees.

2. The annual dues shall be as follows:—

Members and Associates, ten dollars; Juniors, five dollars; Honorary Members and Honorary Asociates, no dues.

3. A member transferred from one grade to another shall pay the difference between the entrance fees of the two grades, and his annual dues shall be those of the grade to which transferred.

4. The annual dues shall be payable in advance on the first day of January. The Secretary shall notify each member of the amount due for the ensuing year at the time of giving

notice for the annual meeting. On notification of his election each member shall pay his entrance fee, but annual dues for the current year shall not be required unless he desires to receive the published transactions of the Society for that year, in which case he shall pay five dollars in addition to the entrance fee.

5. Members and Associates can compound for all future dues and become Life Members or Life Associates by making a single payment of two hundred dollars and signing an agreement to conform to any future amendments to the Constitution and By-Laws.

6. Members are entitled to no return of fees upon severing their connection with the Society.

7. Any member whose dues are more than three months in arrears shall be notified by the Secretary. Should his dues become six months in arrears he shall be again notified by the Secretary and his rights as a member suspended. Should his dues become one year in arrears the delinquent member shall forfeit his membership in the Society unless the Council may deem it expedient to extend the time of payment.

8. The Council may, in its discretion, temporarily suspend the annual payment of dues by any member whose circumstances have become such as to make such payment impossible, and may, under similar circumstances, remit the whole or part of dues in arrears.

9. No name shall be entered on the rolls as Member, Associate or Junior, nor shall the privileges of membership be enjoyed until the payments required in paragraphs 1 to 4 of this article have been made; if the payment be delayed for more than six months from the date of election, the same shall be void unless the Council otherwise direct.

10. (1) Should the expulsion of any member be judged expedient by five or more members, they must draw up and sign a proposal requesting such expulsion, delivering the same to the Secretary, to be laid before the Council.

(2) If the Council do not find reason to concur in the proposal, no entry thereof shall appear in the minutes, nor shall any public discussion thereon be permitted.

(3) If, however, the Council find the charges contained in the proposal for expulsion substantiated, the accused member shall be notified and given an opportunity to resign. If he avails himself of this privilege, no entry shall be made on the minutes nor public discussion in the case be permitted. But if he declines to resign and offers no satisfactory explanation of the charge, the whole case shall be submitted to a special meeting of the Society.

(4) If two-thirds of the members at this special meeting (providing there be not less than twenty present) vote for expulsion, the Chairman of the meeting shall cause the accused to be expelled from the Society, and direct the Secretary to notify the accused of this action.

Article IV.

Officers.

1. The officers of the Society shall consist of a President, Past Presidents, Honorary Vice-Presidents, twelve Vice-Presidents, twenty-four members of Council, and a Secretary and Treasurer.

2. Both Members and Associates are eligible for the offices of President, Honorary Vice-President, Vice-President and members of Council, but three-fourths of the Council shall be Members.

3. Prior to the date of the annual meeting of the Society of the year with which the term of the President expires, the Council shall nominate a candidate for the office of President, whose name shall be presented to the Society for election at the annual meeting. Any other candidate whose nomination, signed by at least sixty Members and Associates, shall have been submitted to the Secretary prior to the annual meeting shall also be presented. The candidate receiving the highest number of votes shall be the President for the ensuing three years. The first President under this rule was elected at the annual meeting in 1906 and his term of office began January 1, 1907. The President shall not be eligible for election as his own successor.

4. (1) The term of office of the Vice-Presidents shall be three years. The terms of the Vice-Presidents which, under a previous provision of the Constitution, should have expired in 1911 and 1912 are regarded as having expired on December 31, 1911. Those terms which, under the same conditions, should have expired in 1913 and 1914 are regarded as having expired on December 31, 1912; those which should have expired in 1915 and 1916 are regarded as having expired on December 31, 1913. Beginning with the four Vice-Presidents elected for the term ending December 31, 1914, there shall be four Vice-Presidents elected each year to take the place of those whose terms expire. The Vice-Presidents to fill the vacancies occurring each year in any class shall be elected by the Council from their own membership. Retiring Vice-Presidents shall be eligible for re-election.

(2) Honorary Vice-Presidents shall be chosen from the list of Vice-Presidents who have had at least ten years' service as Vice-President. They shall be chosen at the meeting of the Council next prior to the annual general meeting of the Society and must be the unanimous choice of all members of Council present. Not more than two Vice-Presidents may be elected Honorary Vice-Presidents in any one year.

5. (1) The term of office of the Members and Associate Members of Council shall be three years. Prior to August 1 of each year the Secretary shall mail to each Member and Associate a list of the names of the Members and Associate Members of Council whose terms expire with the current year, and shall enclose a blank on which each Member may, if he so desires, nominate one additional candidate for Member of Council and one additional candidate for Associate Member of Council; and each Associate Member may, if he so desires, nominate one additional candidate for Associate Member of Council. No nominations received by the Secretary after August 31 shall be considered.

(2) Prior to September 1 of each year the President shall appoint a nominating committee of five, at least three of whom shall be Members. This committee shall scrutinize the nomination slips sent in by Members and Associates and prepare a ballot. This ballot shall contain the names of all the retiring Members and Associate Members of Council who shall not have declined re-election and a sufficient number of additional names to make a total of nine candidates for Member of Council and three candidates for Associate Member of Council. The names listed on the ballot, other than those of retiring Members and Associate Members of Council, shall be chosen by the nominating committee from those who have received the highest number of votes on the nominating lists returned by members of the Society.

(3) Should the number of names which have received at least ten votes in the case of nominees for Members of Council and five votes in the case of nominees for Associate Members of Council be insufficient to complete the number on the ballot list above provided for in sub-paragraph (2), the nominating committee shall add enough names to bring the

total on the ballot up to nine candidates for Member and three candidates for Associate Member of Council.

(4) The ballots shall be sent by mail as soon as possible after September 1 of each year to all Members and Associate Members of the Society. Each Member may vote for not more than six Members of Council and two Associate Members of Council, and each Associate may vote for not more than two Associate Members of Council. The ballots shall be returned by mail to the Secretary and canvassed by a committee of three members appointed by the President. This canvassing committee shall report the results of the election to the Council at its meeting immediately prior to the annual meeting of the Society.

(5) When the ballots have been sent out by the Secretary, should there be a desire on the part of Members or Associates to suggest another list of candidates for the Council, any twenty Members and Associates may unite in submitting another list to the Secretary which shall also be sent out to the membership to be considered in connection with the list already sent. In any event, the six Members who receive the highest number of votes shall be declared elected Members of Council, and the two Associates receiving the highest number of votes shall be declared elected Associate Members of Council, in each case for a term of three years.

6. A vacancy in the office of President shall be filled by ballot by the Council from the list of Past Presidents, Honorary Vice-Presidents and Vice-Presidents until the end of the year in which it occurs. At the annual meeting of that year a new President shall be elected for three years in the manner prescribed in paragraph 3. A vacancy in the office of member of Council shall be filled by the Council for the unexpired portion of the term of the Member or Associate causing the vacancy.

7. The President, Past Presidents, Honorary Vice-Presidents and Vice-Presidents shall be *ex-officio* members of Council.

8. The Council may hold meetings subject to the call of the President, as often as the interests of the Society may demand.

9. At all meetings of Council seven members shall constitute a quorum.

10. The Secretary and Treasurer shall be elected annually by the Council, but may be removed at any time by a majority vote of the Council after due notice has been given.

11. The Secretary must be a Member of the Society.

Article V.

Management.

1. (1) The President shall have general supervision over the affairs of the Society, appoint special committees, and preside at the annual general meetings. He shall be *ex-officio* member of all committees.

(2) In the absence of the President, one of the Past Presidents, Honorary Vice-Presidents or Vice-Presidents, in the order of seniority as determined by original accession to, or election in, their respective grades, shall preside and perform all the duties of the President; where there is the same date of seniority, the alphabetical order will govern. Provided, however, that for the annual meeting of the Society or for any other special occasion when it is known that the President cannot attend and preside, the Executive Committee shall, in its discretion, select and designate as Acting President any one of the Past Presi-

dents, Honorary Vice-Presidents, Vice-Presidents or members of Council, who shall act for the President in his temporary absence and shall perform all the duties which would devolve upon that officer during such Annual Meeting or on such special occasion.

2. (1) The direct management of the Society shall be vested in an Executive Committee of seven, composed of five members of Council, elected annually by the Council, and the President and the Secretary of the Society *ex-officio*. At least three of the five elective members of the committee shall be Members of the Society.

(2) Meetings of the Executive Committee may be held at any time, subject to the call of the Chairman; and four members shall constitute a quorum for the transaction of any business that may be properly brought before the Committee.

3. The Executive Committee shall manage the affairs of the Society in conformity with the laws under which it is incorporated and the provisions of this Constitution. It shall direct the investment and care of the funds of the Society; make appropriations for specific purposes; arrange for the reading and publication of professional papers; take measures to advance the interests of the Society, and generally direct its affairs under such regulations as the Council may from time to time prescribe.

4. The Executive Committee shall make an annual report to the Society, transmitting the report of the Secretary and Treasurer, and of any special committee which may have been ordered.

5. (1) The Secretary shall be the Executive Officer of the Society under the immediate direction of the President and the Executive Committee.

(2) He shall prepare the business for the annual meetings and record the proceedings thereof.

(3) He shall be responsible for all expenditures and certify the accuracy of all bills or vouchers upon which money has been paid, and he shall conduct the correspondence of the Society and keep full records of the same.

6. The Treasurer shall see that all money due the Society is collected and carefully invested in such manner as the Executive Committee may direct. If considered advisable by the Council, the duties of Treasurer may be performed by the Secretary.

7. The accounts of the Secretary and Treasurer shall be audited annually in such manner as the Executive Committee may direct.

Article VI.

Meetings.

1. There shall be at least one annual general meeting of the Society for the reading and discussion of professional papers, election of officers for the ensuing year, and transaction of such other business as may be brought before it. The time and location of this meeting shall be determined by the Council at least three months prior to the date fixed.

2. Special meetings may be called by the Executive Committee at the request of twenty members, which request shall state the purpose of the meeting. The call for such meetings shall be issued ten days in advance, and shall state the purpose thereof. At these meetings thirty members shall constitute a quorum.

3. The Society may adopt, from time to time, such rules as it may think proper for the order of business at its meetings.

Article VII.

Regulations and By-Laws.

1. The Council shall have authority to establish such by-laws and regulations as may be necessary for the government of the Society in the conduct of its affairs, provided that such by-laws and regulations do not conflict with the provisions of this Constitution and that they are approved by a two-thirds vote of the members of Council present at any meeting regularly called for the consideration of same. If, however, objection be made by any member of Council to a by-law or regulation so proposed, it must be submitted in writing for the action of the entire Council and will not be finally adopted unless a majority of the Council signifies its approval.

Article VIII.

Amendments.

1. Proposed amendments to the Constitution must be reduced to writing and signed by not less than ten members. They shall be forwarded to the Secretary at least ten days before the annual general meeting, and shall be immediately forwarded to the Council for its consideration. If a majority of the Council approve the proposed amendment it shall be presented to the Society at the next ensuing general meeting for discussion; if approved by two-thirds of the members present, voting by ballot, if a ballot be demanded, it shall be adopted.

INTRODUCTORY PROCEEDINGS

MINUTES OF THE TWENTY-FOURTH ANNUAL MEETING OF THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS, HELD AT THE ENGINEERING SOCIETIES BUILDING, NEW YORK CITY, THURSDAY AND FRIDAY, NOVEMBER 16 AND 17, 1916.

FIRST SESSION.

THURSDAY MORNING, NOVEMBER 16, 1916.

The President, Mr. Stevenson Taylor, called the meeting to order at 10.30 a.m.

THE PRESIDENT:—I am very sorry there are not more here. I rather expected a larger meeting this morning, but time is pressing and we must go on with the regular business.

I first wish to say that I have a letter from Admiral Capps, in which he regrets very much that duty has called him far away from the city at this time, and he sends cordial remembrance to his colleagues of the Council and the Society. I know that you will regret his absence as much as I do.

I will ask the Secretary-Treasurer to present his annual report.

Mr. Cox presented the following report:—

REPORT OF SECRETARY-TREASURER.

NOVEMBER 15, 1916.

To the Council of The Society of Naval Architects and Marine Engineers:—

GENTLEMEN:—I have the honor to submit the following report showing the condition of the Society at the close of the fiscal year ended October 31, 1916.

The membership of the Society November 1, 1916, was as follows:—

Class of Members.	Membership, November 1, 1915.	Elected at 1915 Meeting.	Promotion, Associate to Life Associate.	Promotion, Associate to Member.	Suspended by Council.	Members at close of Annual Meeting, 1915.	Deaths, 1915-1916.	Resignations, 1915-1916.	Membership, November 1, 1916.
Members	584	24	—	—1	4	603	5	11	587
Associates	184	10	—1	+1	5	189	1	10	178
Juniors	12	9	—	—	1	20	—	—	20
Life Members	6	—	—	—	—	6	1	—	5
Life Associates	4	—	+1	—	—	5	—	—	5
Honorary Members	1	—	—	—	—	1	—	—	1
Honorary Associates	2	—	—	—	—	2	—	—	2
Totals	793	43	—	—	10	826	7	21	798

RECEIPTS.

From November 1, 1915, to October 31, 1916, inclusive.

Entrance fees of new members for the year ending December 31, 1916:—		
Life Associate	$200 00	
Members	200 00	
Associates	90 00	
Juniors	45 00	
		$535 00
Dues for the year ended December 31, 1916:—		
Members and Associates	$6,550 00	
Juniors	80 00	
		6,630 00
Dues for the year ended December 31, 1915:—		
Members and Associates	$690 00	
Juniors	15 00	
		705 00
Dues for the year ended December 31, 1914:—		
Members and Associates	$190 00	
Juniors	5 00	
		195 00
Dues for the year ended December 31, 1913:—		
Members and Associates		110 00
Dues for the year ended December 31, 1912:—		
Members and Associates		32 00
Dues paid in advance for the year ending December 31, 1917		55 00
Recovered dues from reinstated members		60 00
Advanced dues paid by Life Member		100 00
Sales of Publications:—		
Society transactions to members and dealers	$1,098 00	
Special editions of papers	177 01	
		1,275 01
Exchange on remittances, members' dues		1 90
Banquet, Annual Meeting, 1915		1,600 65
Banquet, Annual Meeting, 1916		125 00
Sale of office material		12 00
Proceeds from certificates of deposit used for investment		3,000 00
Interest:—		
From investments	$730 00	
From certificates of deposit and bank balances	237 52	
		967 52
Total receipts		$15,404 08
Balance, cash in bank and on hand, November 1, 1915		4,454 38
		$19,858 46

STATEMENT.

DISBURSEMENTS.

From November 1, 1915, to October 31, 1916, inclusive.

Publications:—		
Printing Volume 23	$4,305 39	
Membership year book	267 94	
Forwarding volumes and papers	47 03	
Storage of volumes	117 90	
Miscellaneous printing	71 03	
		$4,809 29
Rent of safe deposit box, Franklin Trust Company		5 00
Expenses, 23rd Annual Banquet, November, 1915		1,434 10
Expenses, 23rd Annual Meeting, November, 1915		445 45
Expenses, 24th Annual Meeting, November, 1916		29 10
Exchange on remittances, members' dues		5 78
Salaries and clerical expenses		1,380 00
Audit of books and accounts to November 1, 1915		180 00
Rent of Society rooms		490 00
Office expenses, postage, stationery, etc.		550 14
Engineering Congress		720 00
Accrued interest on bonds purchased for investment		160 06
Investment, purchase of bonds		8,308 75
Total disbursements		$18,517 67
Balance cash, October 31, 1916:—		
In Franklin Trust Company	$1,224 64	
On hand	116 15	
		1,340 79
		$19,858.46

DEATHS (7).

Life Member (1).

William H. Jaques.

Members (5).

Darwin Almy.
James M. Lincoln.
William Nish.
William A. Perry.
James C. Wallace.

Associate (1).

Ralph D. Williams.

RESIGNATIONS (20).

Members (11).

Charles H. Bedell.
Walter A. Clark.
John F. Friebele.
Thomas W. Jackman.
Parker H. Kemble.
John C. Leonard.
Walter S. Leland.
James Montgomerie.
Siegfried Popper.
C. Lee Straub.
Laurence M. Thompson.

Associates (9).

Le Roy E. Caverly.
Washington I. Chambers.
C. Lee Cook.
Edward H. Ellison.
William A. Hawgood.
Edward M. McIlvain.
Newman Page.
William F. Piek, Jr.
William T. Sitt.

The following delinquencies exist in the payment of dues:—

For the year ended December 31, 1913:—		
Members	$120 00	
Associates	20 00	
		$140 00
For the year ended December 31, 1914:—		
Members	$240 00	
Associates	70 00	
		310 00
For the year ended December 31, 1915:—		
Members	$510 00	
Associates	150 00	
Juniors	15 00	
		675 00
For the year ended December 31, 1916:—		
Members	$1,000 00	
Associates	340 00	
Juniors	15 00	
		1,355 00
Total outstanding dues at October 31, 1916		$2,480 00

Statement of Resources and Liabilities.

RESOURCES.

Membership dues		$2,480 00	
Deductions:—			
Deaths	$20 00		
Resignations	120 00		
Doubtful accounts	200 00		
		340 00	
			$2,140 00
Accrued interest on municipal bonds, due November 1, 1916			157 50
Due from dealers for volumes			607 79
Office furniture and equipment at 30 per cent reduction from cost			885 00
Publications on hand at 50 per cent reduction from cost			5,618 65
Investments:—			
Municipal Bonds, City of New York at par		$12,000 00	
4 Baltimore and Ohio R. R. Bonds, 1933 Convertibles, at cost		3,925 00	
3 Central Pacific Railway Co. Bonds, 1949, 1st refunding at cost		2,651 25	
2 Morris and Essex Bonds, 2,000, 1st refunding at cost		1,732 50	
			20,308 75
Cash on deposit Franklin Trust Company		$1,224 64	
Cash on hand		116 15	
			1,340 79
Total resources			$31,058 48

LIABILITIES.

Annual banquet, 1916, paid in advance	$125 00
Membership fees and dues paid in advance	125 00
Volume 24 paid for in advance	20 00
Total liabilities	$270 00
Society's present worth at October 31, 1916*	30,788 48
	$31,058 48

*By the provisions of the Endowment Fund resolution adopted in 1914, the position of the Society's present worth at October 31, 1916, is as follows:—

Balance at November 1, 1915		$13,130 00
Additions 1915–1916:—		
Membership entrance fees	$635 00	
Investment income	490 00	
		1,125 00
Balance at October 31, 1916, Endowment Fund		$14,255 00
Net assets other than Endowment Funds		16,533 48
		$30,788 48

The financial statements have been verified by Wechsler & Mills, Public Accountants of New York.

Respectfully submitted,

DANIEL H. COX,
Secretary-Treasurer.

Secretary-Treasurer Cox:—The report, as usual, has been printed, and it lies before you. It is, perhaps, unnecessary to read it in detail, but I will point out the salient features of it. The best way to do that, perhaps, is to turn back, as I have done, to a similar report of last year.

As regards the gross membership, it will be gratifying to note, as you will later be informed, that we have a greater number of new applications for membership than we have had before, so that we will start out the coming year with a greater membership than ever.

Regarding the delinquencies in dues, although the amount of these delinquencies looks large, it will be seen by comparison with last year's summary that we are nearly $200 better off in this respect than we were last year.

Now, turning to the bookkeeping end of the report, in the matter of receipts, you will find that taking into account the balance which we had in bank last year, $4,454.38, we have to account for during the year $19,858.46. In these receipts there is one item of $3,000, entered as a receipt, which is a conversion on the Society's books of certificates of deposit that have been on deposit for some time, and which were, as is shown under the heading of "Disbursements," transferred into bonds by the Executive Committee, so that the Society would get more income from that source.

Under the heading of "Disbursements," the expenses of operating the Society have not been very different from preceding years, and we show the balance on hand, $1,340.79; this is as against $4,454.38 last year. An explanation of that is shown in the last item under the heading "Disbursements," which is $8,308.75, being a conversion of $3,000, as explained before, and the addition of some $5,000, which has been invested in bonds also.

Then, perhaps, the most interesting of all is the statement of assets and liabilities and the present worth of the Society. Taking the figure of total resources, for instance, which is $30,788.48, the corresponding figure last year was $28,748. We are some $2,000 better off than we were before.

The Endowment Fund, which was commenced by order of the Council in 1914, has now come to the very presentable figures of $14,255. That fund will be added to by the addition of membership entrance fees, receipts from investment income and other sources, as time goes on.

The President:—You have heard the report of the Secretary-Treasurer. What is your pleasure? Those in favor of its adoption will please say "Aye"; contrary minded, "No." It is adopted.

The gentlemen will please rise, and the Secretary will read the names of those who have passed away during the past year.

The members rose, and the Secretary read the list of members deceased during the year.

The President:—The Secretary will read to you the action taken by the Council on the suggestion of Mr. T. M. Cornbrooks, regarding the appointment of a special committee.

The Secretary:—Mr. T. M. Cornbrooks, of the Maryland Steel Company, during the summer wrote a letter to the Secretary, which was referred to the Council, and the following action was taken:—

In connection with the suggestion of Mr. T. M. Cornbrooks, that a permanent committee be appointed to keep in touch with various matters arising between shipowning and shipbuilding interests, and the different departments of the Government, the Council recom-

mended to the Society that the Executive Committee be authorized to appoint, within its discretion, a special committee to represent the Society in connection with any matter coming before government officials, when it is a proper matter to be so presented.

THE PRESIDENT:—The Secretary will please read the list of new members recommended for election by the Council.

The Secretary then read the following list of names of applicants recommended for election to the grade of Member:—

Members (48).

Arthur C. Besselievre, Naval Architect, Pennsylvania Shipbuilding Company, Gloucester, N. J.

Andrew D. Canulette, General Manager, Slidell Dry Dock and Shipbuilding Company, Slidell, La.

O. C. Chapman, Marine Superintendent, Crew, Levick Company, Land Title Building, Philadelphia, Pa.

H. Jasper Cox, Assistant to Chief Surveyor, Lloyd's Register of Shipping, 17 Battery Place, New York, N. Y.

James A. Eves, Naval Architect, Maryland Shipbuilding Plant, Bethlehem Steel Company, Sparrow's Point, Md.

James French, Chief Surveyor, Lloyd's Register of Shipping, 17 Battery Place, New York, N. Y.

Edward G. Gallagher, Electrical Engineer, Lake Torpedo Boat Company, Bridgeport, Conn.

Howland R. Gary, Manager, Cummings Ship Instrument Works, 110 High Street, Boston, Mass.

Francis J. Gilbride, Assistant Superintendent, Robins Dry Dock and Repair Company, Brooklyn, N. Y.

Edward C. Gillette, Superintendent of Naval Construction, Bureau of Lighthouses, Washington, D. C.

Arthur A. Grant, Marine Superintendent, Freeport and Tampico Fuel Oil Transportation Company, 120 Broadway, New York, N. Y.

Herbert Haslam, Surveyor, American Bureau of Shipping, 66 Beaver Street, New York, N. Y.

Anatol D. Iskols, Designer, General Electric Company, Schenectady, N. Y.

Otto Kahrs, Engineer, Raadhusgatan 1 and 3, Kristiania, Norway.

Henry Meyer, Chief Draughtsman, Merrill Stevens Company, Jacksonville, Fla.

John McInnes, Superintendent of Construction, Bath Iron Works, Bath, Me.

Quincy B. Newman, Lieutenant, U. S. Coast Guard, Washington, D. C.

James F. Paige, Foreman, Engineering Department, Fore River Shipbuilding Corporation, Quincy, Mass.

Albert O. Pegg, Superintendent Engineer Union Oil Company of California, San Luis Obispo, Cal.

Gustav Z. Prochazka, Draughtsman, Fore River Shipbuilding Company, Quincy, Mass.

George G. Raymond, President, Tietjen and Lang Dry Dock Company, Hoboken, N. J.

Edward M. Salmon, Principal Engineer Surveyor, Lloyd's Register Shipping, 17 Battery Place, New York, N. Y.

Thomas D. Scott, Consulting Engineer, Esplen & Sons., Ltd., 81 New Street, New York, N. Y.

Lyndon B. Taylor, Torpedo Engineer, Naval Torpedo Station, Newport, R. I.

William F. Riley, Superintendent, Shenango Steamship Company, Cleveland, Ohio.

William F. E. Usher, Superintendent Engineer, Oregon Steamship Company, 111 Broadway, New York, N. Y.

Francis Walsh, Chief Engineer, S.S. Havana, Ward Line, Pier 13, East River, New York, N. Y.

Charles A. Ward, Jr., Naval Architect, Lake Torpedo Boat Company, Bridgeport, Conn.

John M. Willis, Vice-President Baltimore Dry Dock and Shipbuilding Company, Baltimore, Md.

Richard C. Wilson, Consulting Engineer, 7911 Elm Street, New Orleans, La.

John M. Williamson, Surveyor, American Bureau of Shipping, 66 Beaver Street, New York, N. Y.

Max Willemstyn, Naval Architect, Chester Shipbuilding Company, Chester, Pa.

Alson E. Woodruff, Sr., Chief Estimator, Maryland Shipbuilding Plant, Bethlehem Steel Company, Sparrow's Point, Md.

Samuel W. Wakeman, General Superintendent, Fore River Shipbuilding Company, Quincy, Mass.

Alfred Donovan, Surveyor, Salvage Association of London, 68 Broad Street, New York, N. Y.

Marcus M. Drake, Naval Architect, 17 Battery Place, New York, N. Y.

John Gardner, Chief Engine Draughtsman, Maryland Shipbuilding Plant, Bethlehem Steel Company, Sparrow's Point, Md.

Andrew Macfarlane, Consulting Engineer, 80 Broad Street, New York, N. Y.

Edward Pier, Chief Engine Draughtsman, Harlan & Hollingsworth Corporation, Wilmington, Del.

Ernest F. Rue, Superintendent Engineer, Steamship Department, Vacuum Oil Company, 61 Broadway, New York, N. Y.

Ralph E. Barry, Post-Graduate Work at Columbia, St. George Hotel, Brooklyn, N. Y.

Andrew D. Hunt, Engineer in Marine Department, Westinghouse Machine Company, 168 Broadway, New York, N. Y.

William Katzenstein, Secretary, L. Katzenstein & Company, 358 West Street, New York, N. Y.

John L. Luckenbach, Vice-President, Luckenbach Steamship Company, 44 Whitehall Street, New York, N. Y.

John W. Millard, member of firm of I. W. Millard & Bro., Naval Architects, 17 State Street, New York, N. Y.

James H. Todd, Superintendent of Construction of Hulls, Seattle Construction and Dry Dock Company, Seattle, Wash.

Martin C. Furstenau, Naval Architect and Marine Engineer, 308 Walnut Street, Philadelphia, Pa.

George G. Sharp, Surveyor, American Bureau of Shipping, 66 Beaver Street, New York, N. Y.

Associate to Member (1).

D. Millard Callis, Naval Architect, 1522 Munsey Building, Baltimore, Md.

THE PRESIDENT:—You have heard the names of applicants recommended for election to the grade of Member.

The Secretary then read the following list of names of applicants recommended for election to the grade of Associate Member:—

Associates (23).

Aubrey D. Beidelman, Draughtsman, Fore River Shipbuilding Company, Quincy, Mass.

James B. Bonner, Manager of Sales, Carnegie Steel Company, 1734 Widener Building, Philadelphia, Pa.

Joseph R. Bowles, President Northwest Steel Company, Portland, Ore.

Samuel H. Cornell, Machinery Installing Department, New York Shipbuilding Company, Camden, N. J.

William M. Dobson, Marine Sales Agent, Sitoselo Company of America, Elkins Park, Pa.

John Flodin, Draughtsman, Seattle Construction and Dry Dock Company, Seattle, Wash.

Garland Fulton, Assistant Naval Constructor, U. S. Navy, Navy Yard, New York, N. Y.

Chee S. Hsin, Nan-Yang Middle School, Shanghai, China.

John H. Hyde, President, Hyde Ship Brake Company, 613 Bankers Trust Building, Tacoma, Wash.

Preston S. Lincoln, Box 40, Wareham, Plymouth, Mass.

David W. Niven, Marine Sales Department, General Electric Company, Schenectady, N. Y.

Illarion V. Mishtowt, Captain, Imperial Russian Navy, Naval Attaché, Russian Embassy, 1411 Flatiron Building, New York, N. Y.

Elisha J. White, Superintendent, Tank Shipbuilding Corporation, Newburg, N. Y.

Albert K. Waycott, Vice-President, Bird-Archer Company, 90 West Street, New York, N. Y.

Thomas J. Larkin, Assistant to Superintendent, Fore River Shipbuilding Company, Quincy, Mass.

Frank L. Davis, Draughtsman-in-charge, Engineering Division, Hull Draughting Room, Fore River Shipbuilding Company, Quincy, Mass.

Samuel J. Zeigler, Jr., Assistant Naval Constructor, U. S. Navy, Navy Yard, Boston, Mass.

Edmund R. Norton, Assistant Naval Constructor, U. S. Navy, Navy Yard, Boston, Mass.

Gilbert C. Dohm, Assistant to Naval Architect, Skinner & Eddy Corporation, Seattle, Wash.

Burton H. Downing, Manager, Heater and Marine Equipment Department, Alberger Pump and Condenser Company, 140 Cedar Street, New York, N. Y.

Theodore E. Hammond, Assistant to General Manager, California Shipbuilding Company, Long Beach, Cal.

Vincent Astor, 23 West 26th Street, New York, N. Y.

Frank D. Berrien, Lieutenant Commander, U. S. Navy, The Moorings, Harrison Avenue, Newport, R. I.

THE PRESIDENT:—You have heard the names of applicants recommended for election to the grade of Associate Member.

The Secretary then read the name of one applicant recommended for transfer to the grade of Associate from Junior:—

Junior to Associate (1).

Philip H. Thearle, Draughtsman, Skinner & Eddy Corporation, Seattle, Wash.

THE PRESIDENT:—You have heard the name of the applicant recommended for transfer to the grade of Associate from Junior.

THE SECRETARY:—In addition, the Council, as provided by the Constitution, elected the following Junior Members:

Juniors (5).

Edgar F. Hanford, Draughtsman, George Lawley & Son Corporation, Yacht Builders, Neponset, Mass.

Parr Hooper, Machinist, New York Shipbuilding Company, Camden, N. J.

Carl J. Nordstrom, Draughtsman, Skinner & Eddy Corporation, Seattle, Wash.

Henry J. Roundy, Assistant Marine Superintendent, Lake Torpedo Boat Company, Bridgeport, Conn.

Keith L. Saunders, Assistant Yard Superintendent, Morse Dry Dock & Repair Company, foot of 56th Street, Brooklyn, N. Y.

THE SECRETARY:—The total is 78 for all grades of membership.

THE PRESIDENT:—Gentlemen, you have heard the list of applicants recommended for election as members of the Society to the various grades. I hope they are all here. Is there any objection to these names? If not, they will be considered as approved and elected.

It is my pleasure, gentlemen, to announce the election made by the Council yesterday at its meeting.

For Vice-Presidents, for the term expiring December 31, 1919:— R. M. Watt, A. P. Niblack, W. M. McFarland and J. W. Miller.

For Members of Council, for the term expiring December 31, 1919:— C. P. Wetherbee, J. H. Linnard, C. A. McAllister, W. L. R. Emmet, J. H. Gardner, and H. C. Higgins.

For Associate Members of Council for the term expiring December 31, 1919:— R. A. C. Smith and Albert W. Goodrich.

For the Executive Committee for the year 1917:—W. L. Capps, W. I. Babcock, Andrew Fletcher, W. M. McFarland and F. L. DuBosque.

For the Committee on Papers for the year 1917:—W. M. McFarland, F. L. DuBosque, and W. I. Babcock.

For Secretary-Treasurer for the year 1917:—Daniel H. Cox.

All of which I trust you will approve.

The next matter of business is the address by the president, which I will read to you.

PRESIDENT'S ADDRESS.

Gentlemen, it is my pleasure to welcome you to the twenty-fourth annual meeting of The Society of Naval Architects and Marine Engineers, and I appreciate highly the honor you have conferred upon me by again selecting me to be your president after a constitutional interim.

PAST CONDITIONS.

It does not seem twenty-four years since an ardent few started the organization of this Society, though at times, most of the time indeed, has it seemed that never would American shipbuilding come into its own. We have seen moderate shipbuilding booms come to flourish for a short time and then wither to such proportions that shipbuilding establishments were fortunate to have the building of cars, water-wheels, water-works and other manufactures for the land and government navy work that they might live.

We have seen, within half of the lifetime of our Society, at least half of our large shipbuilding companies in the hands of receivers or reorganization committees. We have also seen several yards starting with great promise but ending in disaster. Through these periods of alternate exaltation and depression, members of this Society have retained their faith that some day the requirements of their country would change these conditions, and that there would arise such a demand for an American merchant marine there would be no faltering in the future.

It was not foreseen, however, that Europe would be almost entirely engaged in the fiercest war of history, bringing about unbelievable conditions, conditions with which our own government or citizens had nothing to do, for they are innocent of causing or participating in the frightful destruction of life and property that at present appalls the world.

These conditions have brought to us the long looked for opportunity to build up our own marine commerce as well as that of other neutral countries, and there is no reason for not availing ourselves to the utmost of this opportunity.

STATISTICS.

This address promises to be mainly one of statistics. Many sources have been examined to determine the probable facts. It has been extremely difficult to obtain exact results, but a careful consideration of all of the sources warrants the figures given here in round numbers, and these figures, though perhaps not exact in themselves, do present existing conditions with sufficient accuracy to justify placing them on the record of your transactions.

AVERAGE PRODUCTION OF SHIPYARDS.

The year 1909 with a production of 1,602,057 tons represents low tide, and the year 1913 with 3,332,882 tons the high tide, therefore the five-year period, 1910-1914 inclusive, fairly represents the average annual production of the shipyards of the world. This average was 2,740,000 tons gross.

	Per Cent.		Tons.
Of this amount the United Kingdom launched about	60	or	1,650,000
Germany launched about	12	or	330,000
U. S. coasts and Great Lakes (rivers not included) launched	9¼	or	253,000
France launched	4½	or	121,000
All other countries, including Great Britain's colonies and Canada, launched about	14	or	385,000
Total			2,740,000

WORLD'S TONNAGE.

In the year ending June 30, 1915, the entire tonnage of the merchant vessels of the world amounted to 49,262,000 tons.

	Per Cent.		Tons.
The United Kingdom owned	43.5	or	21,300,000
United States owned about (excluding rivers and small lakes)	12	or	5,900,000
Germany owned	10	or	5,000,000
France owned less than	5	or	2,300,000

Taking the greatest tonnage of merchant vessels launched by any nation in any one year of all the years 1899 and including 1915, and combining same, we have a fair estimate of the capacity of the world's shipyards.

			Tons.
These figures give a total capacity of			3,685,000
Of which the	Per Cent.		
United Kingdom, colonies and Canadian Lake ports launched	54	or	1,984,000
United States coasts and Great Lakes	14.6	or	540,000
Germany	12.4	or	465,000
All other countries	19	or	696,000

CONDITIONS IN 1914.

In 1914 the building of merchant vessels was reduced by the European war to a minimum in all countries, the nations at war turning their attention almost entirely to the building of war vessels or munitions, while in the neutral nations it seemed as though marine as well as all other merchant business had come to an end; but in the last two years there has come a mighty change.

The destruction of some and the interning of the remaining merchant vessels of the Teutonic Allies; the commandeering of others by both sides, and the great destruction of merchant vessels of all nations, including neutrals, amounting now to 5,000,000 tons, has so reduced the number of available ocean ships that in order to transport the immense purchases of Europe and to furnish other ocean transportation there has arisen a demand never before seen for old as well as new ships, for anything indeed that could be used for oceanic service.

PRESENT CONDITIONS.

The result has been that in the United States especially every vessel afloat, some extremely old, but every one available for the service, has greatly increased in value; every shipyard has been filled with orders for approximately two years, and many new yards have been established for the building of steel vessels; many old yards that built wooden ships have been resuscitated and many new yards also started for the building of wooden vessels.

We are today, in our own country, in the midst of a shipbuilding boom unequaled in its history. It is to be remembered that command or freedom of the seas, depending on the point of view, is one of the very important causes of the war abroad and that whatever may happen on land, at least Great Britain, Germany, France and Japan have the intention of being prepared, the first to hold and better, if possible, its present superior position, and the others to increase the value of theirs while the United States must now, if ever, regain its once formidable place on the seas of the world. There must naturally from these conditions come a great competition which will enlist all of the skill and efficiency of every nation having a merchant marine.

What is the condition today of the merchant fleets and what will be the tonnage requirements and the capacity of the world's shipyards in 1918? We have seen that the greatest production (the measure of capacity) of the world's yards up to 1915 was 3,687,000 tons. We estimate that in the year 1918 the capacity of the world's shipyards will be about as follows:—

	Tons.	*Increase, per cent.*
United Kingdom, colonies and Canada	2,260,000	14
United States coasts and Great Lakes	826,000	53
Germany	605,000	30
All other countries	809,000	16
Total	4,500,000	23½

	Tons.
The normal tonnage of the world this year amounts to about	50,000,000
Of this there has been a tonnage—	
	Tons
Destroyed	5,000,000
Commandeered	12,000,000
Interned	4,400,000
Total withdrawn	21,400,000
Leaving available at present for regular service not more than	28,600,000

or 57.2 per cent of the normal tonnage, which readily accounts for the present high freights and high values placed on old vessels.

	Tons.
Presuming that peace will be restored by the end of 1917, we have present available tonnage as above	28,600,000
Commandeered and interned ships released	16,400,000
Probable production in year 1917	3,000,000
	48,000,000
Less future destruction, scrapping and depreciation	4,000,000
Leaving an available tonnage of	44,000,000
At the end of 1918, should peace be restored, there will certainly be required	55,000,000

	Tons	
Available at end of 1917, as above	44,000,000	
Estimated construction, 1918	4,500,000	
		48,500,000
Still leaving a tonnage deficit at end of 1918 of		6,500,000

From this it will be seen that high freights and high prices will continue and shipyards will be busy for some years to come, and it behooves all concerned—the government, owners, builders, and shippers—to see that we obtain our share.

As to the increase in an American merchant marine, flying the "Star Spangled Banner," the situation may be quite different, though we still hope not. At present the shipyards of the United States are building nearly 1,500,000 tons of steel and over 50,000 tons of wooden vessels to be finished during the next two years.

Of these at least 500,000 tons are for foreign account, and from reports recently received this tonnage will be increased, so that about one-third of the vessels now contracted for in this country will fly foreign flags, mostly the flag of Norway.

At the present high freights, notwithstanding the high cost of building, owners can well afford to pay the difference between operating under the American flag and that of a foreign country, but possibly future conditions may change the special advantage we now possess.

FOREIGN VESSELS UNDER AMERICAN REGISTRY.

The European war has aided the merchant marine in the number of vessels registered as well as in the number contracted for in American yards. To September 26 last there were in all 196 foreign built vessels of 642,802 tons admitted to American registry, but there were 261 American built vessels of 151,676 tons sold to foreigners, leaving a balance of 491,126 tons, almost 10 per cent increase in tonnage of American registry.

When the war ceases and the competition before referred to commences, it will be the privilege of the United States Government to aid shipowners to obtain their share of the freights then paid, be the same high or low.

THE SHIPPING BOARD.

What sort of protection, if any be necessary, shall be provided, and what changes in existing laws containing burdensome clauses shall be made, remain to be seen, and upon the

lately authorized Shipping Board with its extensive power depends such recommendations to Congress as shall best be enacted.

Announcement has not yet been made of the personnel of this Board, but we have no doubt that it will be of high character and that it will possess a general knowledge of the whole subject. Certainly the Shipping Board will have an opportunity to afford great assistance and encouragement to those who desire to own and man ships to carry our flag over the seas and to do our share of the world's commerce without expending an undue amount of the $50,000,000 appropriated for its use.

A GOVERNMENT SHIPPING COMPANY.

In this connection it is interesting to note the establishment of the Belgian Shipping Company under the auspices of the Belgian Government, with a capital of 50,000,000 francs ($9,650,000), and of which all officers must be Belgian, born in Belgium; all stockholders must be Belgian, and no stockholder can be a partner or director of other companies of which the majority is not composed of Belgians, born in Belgium.

MARINE INSURANCE.

There has been recently one great change favorable to a firm establishment of an American merchant marine. For years the matter of marine insurance has been mostly left to foreign companies. As in other features of our business, we have been too busy with our inland matters to appreciate the worth of attention to marine insurance.

Only six months ago we were told that shipowners must go abroad for their insurance and, having had that habit for years, it still was thought necessary. But we are now in quite a different position, for insurance has been placed in this country for large amounts on single ships, and, wonder of wonders, insurance is being placed here for foreign owners.

UNITED STATES GOVERNMENT INSURANCE.

Here we should note the result of our own Government's operation of war risk insurance. From September 2, 1914, to July 31, 1916, the United States Government issued 1,539 policies, insuring $138,392,389 on American non-contraband cargoes, for which it received $2,904,886, with net losses amounting to $712,578, making a gross profit of $2,192,384. Deducting salaries and operating expenses, $32,982, leaves on policies issued, during twenty-two months, a net profit of $2,159,416.

Perhaps the government cost did not cover all of the charges to which private insurance companies would be subject, nevertheless the experience warrants the careful attention of insurers as well as insured.

NATIVITY OF CREWS.

One of the grave questions that arise in consideration of the American merchant marine is the one concerning crews. We do not suppose that at any time in the past crews of American ships were all native born, but it is quite certain that for a good many years the number of native-born Americans serving on ships has gradually been decreasing. In 1909 about half of the crews on American ships were natives of the United States, while last year the proportion was reduced to 43 per cent. We believe that there still remains

something of the romance of the sea and its sailing ships, and, given a world-wide trade, our ships with power or without will attract more and more of our natives to service on board. We also have the alternative—the employment of those of foreign birth who will become our citizens. Here, as in other industries, the kind of immigration matters greatly. Our laws covering the question of physical and mental fitness must be strictly enforced. It would then seem that our American ships would be attractive to the best of sailors of whatever birth.

COMMITTEES ON FIRE RESISTANCE AND BULKHEADS AND LOAD LINES.

As to your own direct interest as naval architects, two recent movements deserve especial mention. It is to the credit of Hon. William C. Redfield, Secretary of the Department of Commerce, that he called into service naval architects, shipbuilders, owners and operators to aid by conferences in the solving of two very important questions relating to vessels.

The first conference, held last May, on the subject of reducing the fire risk, resulted in the testing by the United States Board of Standards of all sorts of materials that may render construction of vessels fireproof or nearly so. When these tests shall have been completed, the competent committee appointed will report its recommendations.

The second conference, held last September, discussed the subject of subdivision of ships by bulkheads, and the equally important subject of assignment of load lines above which ships must not be loaded.

These subjects were referred to a committee of nine, seven of whom happen to be members of this Society. It is needless to say that this committee, composed of naval architects, builders, owners and the president of the Classification Society, American Bureau of Shipping, will give the subject the most careful attention that it may be able when the time comes to give such information and advice to government officials as they may require.

Subjects like the subdivision of ships by bulkheads, and assignment of load lines, should be, as far as possible, treated as international.

For transoceanic service we should adopt the rules suggested by the Conference on Safety at Sea, held in London in 1913-1914. There still remains what appears more difficult of solution, our own Atlantic coastwise, Pacific coastwise, and Great Lakes services, each of which brings problems of its own, requiring the utmost careful consideration.

THE FUTURE.

"Watchman, tell us of the night, what its signs of promise are!"

We remember too well the conditions that suddenly came upon our country in August, 1914, and the predictions of important men of this community, particularly those of financiers, none of which came true; though it is only fair to say that no prophet arose to say them nay.

In these days, predictions and warnings about the future are made by great men and read with interest, but we hesitate to indulge in prophecy. We realize the great changes that have taken place, the enormous expenditures in Europe, expenditures which are causing such terrible destruction. We find that foreign nations, besides the very large amounts borrowed from their own peoples, have also borrowed from the United States the very considerable amount of 1,796 millions of dollars, which is only a little over 3½ per cent of the total amounts borrowed by the Entente Allies and the Teutonic Allies. These figures illustrate in

brief the financial conditions abroad. As it is confidently predicted on both sides that the war will last at least another year, these conditions will not change for the better.

On the other hand, the United States has within its borders 30 per cent of the world's monetary stock of gold and 2,000 millions of American securities have been returned. Financial conditions are, therefore, reversed and, as a distinguished financial writer truly says, "Within a period of two years New York has assumed a place among international money markets that was undreamed of before."

Foreign nations have thus become debtor nations and our own a creditor nation, but while this condition will last certainly so long as the war continues, it is to be remembered that great nations, as the same financial writer says, "have (after other wars) recovered with amazing rapidity from the devastating effects of war. . . . Great as this war has been and destructive, and wasteful, may it not develop as heretofore that economy, science, invention, education, industrial organization and developments in transportation and banking, applied with stern devotion, will counterbalance its legacy and permit Europe and the rest of the world to grow as it grew in the past?"

This is undoubtedly true, and it applies with especial force to our own land, for we have no direct war legacy to counterbalance.

We again find that necessity is the mother of invention and so science and invention go hand in hand developing processes which render unnecessary certain importations upon which we heretofore depended. Are not our educational institutions developing in a marvelous degree? We certainly can claim a faculty for mechanical invention and for industrial organization second to none. Our capital in a large and broad-minded way is now interested in fostering and extending foreign trade, in a truly American merchant marine, and in a marine insurance that will protect owners and shippers; and as means of travel has always increased travel, so means of trade will increase our trade. Our Federal Reserve banking system will prove an inestimable benefit to our whole country.

There only remains economic efficiency in all of these endeavors to be proven, and, while as a nation we are certainly most extravagant, it cannot be denied that there is a great tendency to economic efficiency in all of our industries.

So far as shipbuilding is concerned, the figures already given for merchant vessels now being constructed and to be hereafter built prove that we are on the eve of great prosperity.

Make from the statistics herein given your own analysis. Mine is to the effect that there is before us a prosperous period of at least five years in which we can improve our facilities and methods so much that there will be no question of our shipyard efficiency and ability to meet competition; provided that our Government and Shipping Board really reason together face to face with our shipowners, shipbuilders and shippers, and determine to adopt the best policy to advance that most necessary and beneficial feature of our industries, an American merchant marine. Let there be no more periods when our grain and produce cannot be delivered for want of American ships, or times when any foreign government shall say what non-contraband can or cannot be shipped from our own ports.

Only the merchant marine service has thus far been considered, but the Navy must not be forgotten. Add to the merchant ships which must be built in our yards the proposed increase in the Navy, for which sixty-six ships of various classes are soon to be contracted for, at an estimated expenditure of $185,560,000, with armor, armament or navy ammunition, for which $66,595,000 more is required. Consider that included in this appropriation are the new battle cruisers, designed by members of this Society. The design of these battle

cruisers is the most wonderful of all steps in the progress of designing skill, for in these ships are massed unprecedented power and unequaled speed and means of offense.

These facts are enough to fire your enthusiasm, but if you have listened with fair attention you have noted that there has been no indulgence in heroics. I trust, however, that you will have observed an underlying note of absolute faith in the future position and prosperity of our country, which must also carry with it the prosperity of those who build, own, operate and use our ships.

I see no chance of failure in the future. We need men, but they will come from the warring nations, tired of their systems of government and rejoicing to become American citizens. Men, too, will be raised to find their opportunity in the steadily alive shipyards of the future.

Our nation will again be a great maritime nation, holding its own among the other great nations of the earth.

To feel otherwise would be a confession that our great republic—now 141 years old—is a failure in self-government, enterprise, industry, efficiency and foresight, an appalling failure in those qualities that make men and great nations. This surely cannot be, it must not be.

The reading of President Taylor's address was greeted with much applause.

The President:—I take great pleasure in acknowledging gratefully the following sources of information for the details in the president's address:—

U. S. Navy Department.
U. S. Department of Commerce.
Hon. E. T. Chamberlain, Commissioner of Navigation.
H. L. Aldrich, International Marine Engineering.
Engineering of London.
Liverpool Journal of Commerce.
New York Journal of Commerce.
Marine Journal of New York.
Sir Norman Hill, President of Liverpool Steamship Owners' Association.
Lloyd's Shipping Agency.
Lloyd's Registry.
American Bureau of Shipping.
War Loans and War Finances issued by the Mechanics and Metals National Bank of New York.

The next in the order of exercises is the reading of papers, and I wish to call to your attention a notice that has been given heretofore, and is still in force, that the reading of papers is limited to five minutes. We have a number of papers, perhaps too many for the time at our disposal, and the enforcement of this rule must be made in order that all of the papers may receive due consideration.

Paper No. 1 is entitled "New Method of Indicating the Density of Smoke as Installed on the U. S. S. Conynham," by Admiral R. T. Hall, U. S. Navy, Member. If the author is present we will be glad to have him come forward and present the paper. As he is not present, we will consider that the paper is read by title.

NEW METHOD OF INDICATING THE DENSITY OF SMOKE AS INSTALLED ON THE U. S. S. CONYNGHAM.

By Rear Admiral R. T. Hall, U. S. N., Member.

[Read at the twenty-fourth general meeting of the Society of Naval Architects and Marine Engineers, held in New York, November 16 and 17, 1916.]

This system was installed on the after stack of the U. S. S. Conyngham and consists of a light transmitter installed on one side of stack, a light receiver installed on opposite side of stack to light transmitter, and an indicating meter with suitable control appliances installed in boiler room.

The indicating meter is provided with a scale of smoke densities, ranging from dark to clear, Plate 2.

This system was in successful operation during the official trial of the vessel and was found to operate satisfactorily under all conditions of smoke.

Scale indications at various densities of smoke were checked up by a member of the Trial Board with observations made visibly from deck and were found to be correct.

The basic principle of operation of the system is dependent on the peculiar property of the metal selenium, this metal, under certain conditions of crystalline structure, being light sensitive in its resistance to a passage of electric current, viz., of low resistance at higher light intensities, and vice versa of high resistance to lower light intensities.

It will be manifest, if a beam of light be projected across a stack, that its intensity will vary with the density of the smoke. It will be further manifest, if a plate of selenium of suitable structure is placed opposite to the source of projected light, its electrical resistance will also vary with the density of smoke, and, by connecting the selenium plate in series with a suitable indicating meter and a source of electric current supply, such variations of smoke density will be made manifest by variation in current flowing through meter and, by suitably arranging the meter scale, such variations in electric current will be indicated as smoke densities.

The installation is shown in elevation and diagrammatically in accordance with Plate 1.

The figure 1 designates the after stack leading from boiler uptake 2; 3 designates a cast composition box rigidly secured to one side of stack, and figure 8 designates a cast composition box also rigidly secured to stack but diametrically opposite to box 3. The stack 1 is provided with apertures as shown in section; 4 designates a cover for box 3, and to which is secured, but insulated from, the selenium plate 5 (Plate 3); 6 designates a glass pane whose function is to protect the selenium plate 5 from accumulation of dust, etc. Means are provided on box 3

for cleaning the face of pane nearest the stack, if found necessary; 7 designates a brass pipe leading from boiler room through box 3 and to the stack and whose function is to provide a steady stream of forced draft air through box 3 and stack, and thereby keep box 3 free from an accumulation of soot.

Box 8 is provided with a slidable sleeve whose function is to vary the focal distance of incandescent lamp 10 and lens 11. Means are provided on box 8 for locking the sleeve in place after the focal distance has been determined. The lens, 11, is rigidly secured to box 8 and means are provided on box 8 for cleaning the lens if found necessary. No. 12 designates a pipe similar to pipe 7, and serves a similar purpose for box 8.

No. 13 designates a metal plate installed in boiler room, in a location readily observable by attendants. On the plate (13) is installed the smoke indicating meter, 15, whose scale is arranged in accordance with Plate 2.

No. 14 designates a potentiometer also installed on the plate, 13. The potentiometer is provided with a slidable brush 18 for adjusting the potential on the selenium plate 5, and serves as a simple and effective means for setting the indicator on the clear indication, as when no smoke is issuing from stack. No. 16 designates a switch rigidly secured to plate 13, but insulated from it, and serves as a means of circuit control to potentiometer 14, meter 15, and selenium plate 5. No. 17 designates a switch similar to switch 16, and for control of incandescent lamp 10.

The system is connected, as shown, to the ship's lighting battle main at 125 volts.

The following general advantages are claimed for the system:—

(*a*) Making it possible for attendants in boiler rooms to observe directly the character of smoke issuing from stack and enabling them to adjust the amount of fuel and air necessary for perfect combustion.

(*b*) Prevention of soot deposition on heating surfaces, such soot impairing the evaporative efficiency.

(*c*) Informs firemen of smoking condition of stacks and serves as a means for elimination of the many objections to same.

(*d*) Elimination of personal error from a naval strategical standpoint in determining smoke densities. At present the recording of smoke densities is dependent on the human vision in comparison to arbitrary shades and colors.

DISCUSSION.

The President:—Is there any discussion on the paper which has just been read entitled, "New Method of Indicating the Density of Smoke as Installed on the U. S. S. Conyngham?" We will be glad to hear from any member who has any views to express on this new method of indicating the density of smoke.

Captain A. P. Niblack, *Vice-President*:—This device is more important than at first sight appears. Destroyers in our Navy are not only required to run smokeless in competitive tests for engineering efficiency, but are, at times, required to make all the smoke possible in order to "screen" tactical movements. The usual method of communicating from the bridge to the fire rooms is by four different telltales, whereby the officer of the deck controls the character of the smoke from each one of the four stacks by communicating with the firemen controlling the boilers which use them. This requires more or less constant supervision and signalling. By the method here described, the fireman may himself keep informed of what his fires are doing as to smoke.

The use of smoke as a "screen" has a very definite advantage and purpose at certain times, and this device works both ways, not only to aid in determining how little smoke, but how much smoke is being emitted from the stacks.

Rear Admiral Hall (Communicated):—This device makes it possible to determine the character of smoke at the base of the stack and to regulate the fires for maximum efficiency.

Combustion is more completely and easily governed by observing smoke control than by observing flue gas analysis.

The following data, taken from a test on a Babcock and Wilcox boiler, the stack from which was fitted wih mirrors for determining the character of the smoke, show comparison made with smoke charts:—

	Test No. 3.	*Test No. 4.*	*Test No. 5.*	*Test No. 6.*
CO_2	11.57	11.86	10.71	10.94
CO	.04	.04	.02	.00
Oxygen	4.50	4.08	5.18	4.73
Nitrogen	83.89	84.02	84.09	84.33
Smoke	1.3	1.5	2.3	1.15
Water per pound of oil	15.72	15.86	14.12	15.44
Boiler efficiency	79.50	80.21	71.41	78.08
Oil burned per hour (pounds)	1,202	666	1,922	1,947

In tests 3, 4 and 6, control of fires depended on the character of the smoke and was kept practically constant. In test 5 control of fires was dependent on gas analysis.

In tests 5 and 6 the amount of oil burned was approximately the same. The following are comparative results in favor of smoke control over gas analysis control:—

	Test No. 5.	*Test No. 6.*
Pounds oil burned per hour	1,922	1,947
Water evaporated per pound of oil	14.12	15.44
Boiler efficiency (per cent)	71.41	78.08
Gain in boiler efficiency by smoke control (per cent)	.....	6.67

The President:—On behalf of the Society, I will extend thanks to Rear Admiral Hall for this interesting paper.

We will now take up paper No. 2, entitled, "Salvage Equipment Used in Raising Submarine F-4," by Naval Constructor J. A. Furer, U. S. Navy, Member.

Naval Constructor Furer presented the paper.

SALVAGE EQUIPMENT USED IN RAISING SUBMARINE F-4.

By Naval Constructor J. A. Furer, U. S. N., Member.

[Read at the twenty-fourth general meeting of the Society of Naval Architects and Marine Engineers, held in New York, November 16 and 17, 1916.]

The salvage methods used in raising wrecked vessels may be divided broadly into two classes. The most commonly applied method consists of restoring the buoyancy of a sufficient number of flooded compartments to float the vessel. This can be done in a number of ways. The usual method is for divers to make temporary repairs to the damaged underwater body. The compartments affected are then pumped out. More recently, successful wrecking jobs have been accomplished by sealing the decks over the flooded compartments and expelling the water through the damaged bottom by means of compressed air supplied from a tender. In cases of ordinary grounding, where perhaps no serious damage has been done to the underwater body, the vessel can often be sufficiently lightened by transferring or jettisoning enough cargo, or other heavy weights, to permit hauling the ship off at high tide. All of these methods fall under the general head of restoring lost buoyancy.

The second method consists of mechanically lifting the sunken vessel off the bottom and towing it into shallower water, or into dry dock, suspended from the lifting apparatus. This method, while it is not applicable to very large vessels, may be the only method possible under the circumstances. This was the salvage method that had to be used in raising the F-4.

The submarine failed to return from a submerged run made outside of Honolulu Harbor on March 25, 1915. The vessel was definitely located on the following day, in 304 feet of water. After making a number of fruitless attempts to drag the submarine into shallower water by means of sweeps, it became apparent that direct lifting was the only practicable salvage method.

DESCRIPTION OF WINDLASS SALVAGE METHOD.

The problem consisted of lifting 260 tons, the submerged weight of the submarine. Ordinarily, in the lifting method, surface pontoons are used for salvaging sunken craft. The lifting cables or chains are taken to the pontoons and are hove as taut as possible at low tide. As the tide rises the buoyancy of the pontoons lifts the craft clear of the bottom. The pontoons with their suspended load are then towed into shallower water until the wreck is again grounded. At the next low tide the chains are again hove taut and the process is repeated. Generally, also, the pontoons are equipped with flooding and pumping arrangements so as to increase the lift that can be obtained at each tide.

Salvage pontoons of this kind were not available in Honolulu. They would not have been altogether suitable in any case, because the difference between high water and low water off Honolulu is only about 1½ feet, and therefore practically all of the lift would have had to be accomplished by the difference in draught of the pontoons when flooded and when dry. As there is always a considerable amount of slack to be removed from lifting gear before it takes up the load, the result would have been a very limited lift at each step, if this type of pontoon had been used.

There were, however, on hand locally, two bottom dumping mud scows of rugged construction. These scows were 104 feet long by 36 feet beam by 13 feet deep. The scows had four mud-pockets, each about 24 feet by 13 feet at the top and sloping to 11 feet by 13 feet at the bottom. These scows were selected for the weight-carrying units of the salvage plant. Details of the scows are shown in Plates 11 and 12. The scows were of ample strength and capacity to carry the load when distributed to the main strength members of the structure. Their adaptation for the job consisted of providing them with suitable lifting gear.

Briefly, the salvage method consisted of sweeping four wire hawsers under the vessel—two forward and two aft. The ends of these hawsers were brought up through the central mud-pocket openings of the scows and were then attached to specially constructed windlasses mounted over the pockets. Two windlasses were installed on each scow, one for each hawser. By winding up the hawsers on these windlasses the vessel was thus lifted in the loops of the four slings.

DESCRIPTION OF EQUIPMENT SCOW.

Five 30-inch, 100-pound I-beams were used for the windlass foundations on each scow. Three heavy angles were fitted across the tops of the I-beams to resist racking. The ends of the beams were secured to the mud-pocket coamings by drift bolts and were braced by 12-inch by 12-inch timbers. The middle I-beam was supported throughout its length by the division bulkhead between the two central pockets. The two I-beams at the ends were supported by a timber truss for transferring part of the load to the mud-pocket framing of the scows.

The windlasses were made from sugar-mill shafts which were found in stock in Honolulu. These shafts were 13 feet long by 14⅝ inches diameter, after being turned down. The shafts themselves formed also the barrels of the windlasses. Although a diameter of 15 inches is far too small to fulfil the theoretical requirement for winding up cables of the size used, it nevertheless proved satisfactory. Of the four slings two were of plow steel. These stranded to some extent, but in no instance did a cable fail entirely, due to the short nip resulting from the small radius of the bend over the windlass barrel. This impairment ruined the cables for further use over the length affected, but this was a small matter as compared to the cost and difficulty of building windlasses conforming in diameter strictly to theoretical requirements.

The turning effort was applied to the windlasses by means of a bull wheel fit-

ted to one end of each shaft. The wheels were built up solid of such steel plates as were locally available. The material used consisted of ten ½-inch plates for the core, with ¾-inch plates for the cheeks. The core was lined with Douglas fir so as to provide a reasonably smooth barrel for the bull rope.

The windlasses were supported by three cast-iron pillow blocks bolted to the I-beams. Instead of fitting caps over the bearings to keep the shafts from rolling out, two 1¼-inch nickel steel U-bolts were fitted over the journals adjacent to the bull wheels, with an additional U-bolt over the middle bearings. The tendency for the windlasses to leave their bearings existed only when the bull wheels were locked during the fleeting operation mentioned below. If it had been feasible to lock the shafts at both ends at a radius greater than the radius of the line of action of the lifting hawsers, no such tendency would have existed. As it was, an uncompensated moment tending to roll the windlasses out of their bearings existed with the hoisting slings in certain positions, namely, when the line of action of the active forces lay outside of the triangle formed by the three bearings and the locking pin support. The U-bolts proved adequate, except in one case, when a shackle in the running gear carried away, permitting the windlass to back down suddenly on to the locking pin. The U-bolts in this case snapped off and the windlass jumped the bearings, fortunately without doing much damage.

Power was supplied on each scow by a two-drum 8-inch by 10-inch hoisting engine. The drum lines consisted of ¾-inch plow steel wire rove up to triple blocks. The running block of the purchase was shackled to the bull rope. This purchase, in conjunction with the multiplication of power due to the diameter ratio of the bull wheel and windlass barrel—namely, 50 to 15 inches—was sufficient to wind up the load on one of the scows. On the other, due to the design and condition of the engine, a luff had to be clapped on to the purchase to further multiply the power. The distance between the triple blocks placed a limit of three turns on the number of revolutions of the windlasses obtainable without fleeting the tackles and rewinding the bull ropes. When the running blocks of the purchases had reached the end of their travel, the windlasses had to be locked to keep them from unwinding. The purchases were then overhauled by means of 4-inch manila lines taken to the nigger-heads of the engines. The bull rope was now unshackled, rewound on the bull wheel by hand, and again shackled to the running block of the purchase ready for another lift. The large lead block for the bull rope is shown in Fig. 1, Plate 4. These lead blocks were built specially for the job and were so designed that the bull-rope socket could be dropped through the score of the block without coming up on the cheeks.

The locking device for the windlasses consisted of a nickel steel pin slipped through a hole in the bull-wheel disc and supported by pillow blocks resting on the foundation I-beams. Four holes were bored in the wheels so as to make it possible to lock the windlasses every quarter turn. A pawl and ratchet would have given a greater range of locking positions, but would have introduced undesirable elaboration into the design and construction of the gear.

In order to provide a margin of reserve power for starting the vessel, provision was made for using the buoyancy of the scows. A flood valve was fitted in the bottom of each scow and pumps were installed on deck for unwatering. Stability calculations indicated that the scows would be unstable with the load suspended from the windlass shafts because of the internal free water surface. In order to counteract the upsetting moment due to the negative metacentric height under these conditions, should it become necessary to flood the scows, heavy timber cribbing was fitted around the bottom of the mud-pockets for restricting the swing of the lifting hawsers. This timber cribbing also served the purpose of protecting the structure of the scow itself from the cables. The cribbing consisted of 12-inch by 12-inch Douglas fir timbers. It was found necessary to flood a scow only once—to relieve the strain on a jambed hawser. Figs. 1 and 2, Plate 4, show some of the details referred to above.

LIFTING HAWSERS.

Six cables as follows, each from 900 to 1,000 feet long, were used for lifting at one time and another:—one 2⅝-inch plow steel, one 2-inch plow steel, two 2½-inch galvanized crucible steel, and two 2¼-inch galvanized crucible steel hawsers.

The two plow steel hawsers, especially the 2⅝-inch hawser, proved the most satisfactory, because they resisted chafing to a much greater degree than galvanized wire. On the other hand, the plow steel cables were much harder to handle and to sweep because of their stiffness. Splicing the plow steel cables proved quite difficult, much more so than splicing the galvanized cables. The 2⅝-inch plow steel cable showed a somewhat greater tendency to strand at the windlass shafts, due to the short nip, but the stranding was not sufficient to cause the cables to part at the upper end.

The hawsers were attached to the windlasses by means of 2½-inch hook bolts. These hook bolts were fitted through holes drilled in the shafts close to the bearings, as will be noted from the plans and photographs. By setting up on the nut of the hook bolt the hawsers were squeezed down on the shafts and thus kept from slipping by friction. The hawsers were further backed up by two cable clamps secured close to the hook bolts. On several occasions the hawsers started to slip through the hook, but held as soon as the cable clamps took up. Three dead turns of the lifting hawsers were allowed before taking up the load.

DREDGE USED AS WORKING BASE.

On account of the great depth of water, it was impracticable to anchor the scows over the submarine while securing the lifting slings to the windlasses. Also, the scows did not have on board a power plant and other facilities for taking care of the small jobs constantly arising. It was therefore necessary to have a well-equipped wrecking craft anchored in the immediate locality of the vessel which could be used as a base for conducting the salvage operations. A dredge equipped

with an adequate power plant, including a dynamo, was used for this purpose. The dredge had a 10-inch by 14-inch hoisting engine geared to six drums, any one of which could be used independently of the others. The deck leads were so arranged that drum lines could be taken over the ends and sides of the craft advantageously.

From previous experience in attempting to anchor where the submarine lay, it was obvious that the dredge could not be moored in the customary manner on account of the great depth of water to seaward. The expedient adopted was to use the submarine itself as the seaward anchor. This was accomplished by sweeping a wire hawser around both the bow and the stern of the vessel. These hawsers were taken over the end log of the dredge and were secured to timber heads by chain stoppers, or to the drum lines. The inshore mooring for the dredge consisted of an anchor with a wire anchor line leading to one of the drums.

Plain wire hawsers of the sizes mentioned were first used for lifting the submarine. These hawsers were swept under the vessel by tugs. The ends were then temporarily transferred to the dredge. Divers were sent down after each line was swept into place to report on its position. Considerable difficulty was experienced in locating the lines correctly at the great depth in which the vessel lay.

The diving on this job established a new record. The Bureau of Construction and Repair had been experimenting with deep-sea diving for some time prior to the loss of the F-4. It so happened that these experiments, together with the development of the special equipment needed, were brought to successful termination just before the accident. A party of specially trained men was sent to Honolulu from the New York Navy Yard, where the experimental work had been done.

After the first few dives it was realized that the divers would not be able to do manual work at this great depth, because of the extreme exhaustion following such work. This is not so surprising when it is remembered that at 300 feet a diver is breathing air under 135 pounds pressure. The experimental work which had been done indicated also that it was not safe to keep divers on the bottom at this depth for any great length of time. On this job the men were not kept on the bottom intentionally more than from 10 to 15 minutes at a time. It was fortunately not found necessary to call on the divers to do manual work while the vessel was in deep water. Their function consisted of observing the location of the lines and reporting on the steps necessary to bring them into the positions desired. Their services in this connection were invaluable, as it would not have been possible to have adjusted the slings without their reports.

All four hawsers were finally swept into position and were transferred to the scows. Some time had elapsed since the first hawser had been placed under the submarine, consequently this first line was no doubt considerably chafed before lifting operations were started. Such impairment was considerably augmented at just this time by bad weather, which increased the motion of the scows and dredge. After lifting about 12 feet and towing inshore a corresponding amount, one of the galvanized hawsers parted. On being brought to the surface it was quite evident that the stranding had occurred at the bilge keels. Its replacement was some-

what delayed by the weather, but this was finally accomplished and another lift was made. A hawser again parted and could not be immediately replaced on account of bad weather. While the scows were riding out the weather, one cable after another parted, the last to go being the 2⅝-inch plow steel cable. Altogether a lift of 25 feet was accomplished with the wire hawsers.

CHAIN SLINGS.

In view of the rapid impairment of the cables by chafing, a 15-fathom shot of chain was next inserted in the middle of each sling where it passed under the submarine. For this purpose 2⅝-inch stud link anchor chain was used. The broken hawsers were used for the pendants of the slings. Considerable difficulty was experienced in sweeping the combination chain and wire slings into place, partly because the position of the submarine had been shifted and it now lay with one propeller buried in the sand. After working twenty-one days all four slings were again in place and lifting operations were resumed.

Good progress was made in hoisting and towing to shallower water. A depth of 50 feet was reached close to the harbor entrance, when a heavy ground swell and bad weather set in very suddenly and wrecked the whole operation. In order to save the scows from being washed up on the reef the hoisting slings had to be cast off and the scows towed into the harbor. After a number of days the sea calmed down sufficiently to permit divers to examine the vessel. They reported that the shell had collapsed in the wake of the former position of the forward slings. This was caused by the violent surging of the forward lifting scow in the surf waves just before the slings were cast adrift.

On taking into consideration various phases of the situation, it was decided to change the plan of operations. In the first place, the months of June and July are the surf months on the south side of the Island of Oahu. A heavy swell can, therefore, be counted on most of the time during these months, off the entrance to Honolulu Harbor. It was considered likely that new lines could not be placed under the submarine and taken to the scows in the short intervals of smooth weather. This operation, from previous experience, was apt to take a number of days, hence there was danger of getting caught suddenly at any time as before.

The strongest reason, however, for changing the salvage plan was that the submarine might break in half while being taken through the channel, if lifted by the scows. This would have blocked the harbor to navigation. To have attempted repairs to the ruptured section, in order to permit using the former method of lifting, would have involved great expense and much delay, with no assurance of success. The work would have had to be done by divers and would have been made exceedingly difficult by the undertow.

There was no water shallower than about 40 feet in which the vessel could be landed. This was the governing factor in planning the new salvage method. The maximum draught which the floating dock in Honolulu can take is about 25 feet

6 inches. If there had been a gradual slope of hard bottom in other than the ship channel, from the resting place of the vessel to the dock, it might have been possible to use the customary pontoon method, whereby vessels are lifted 5 or 6 feet at a time and are towed to a new landing between lifts. This plan would have called for at least one landing directly in the channel. If trouble had been experienced in making the next lift promptly, the channel would have been blocked to navigation. In the harbor itself the bottom is soft, due to silting from streams and sewers. To have landed the vessel in mud would have been extremely hazardous, because mud suction practically doubles the weight to be lifted. Furthermore, the vessel would have filled completely with mud through the large aperture, as the canvas mats placed by the divers could not be counted on to keep the opening sealed.

SUBMERSIBLE PONTOON METHOD.

It was therefore necessary to resort to a salvage method which would provide for lifting the vessel from a depth of 50 feet to a depth of not more than 25 feet at one step. The use of submersible pontoons offered the best solution of the problem. The plan adopted called for the use of three pontoons on each side of the vessel connected in pairs by chains passing under the boat and up through hawse pipes in the pontoons. The disposition of the pontoons is shown in Plate 13.

The principal considerations which governed the design of the apparatus and the plan of operations were:—

(*a*) A sufficient factor of safety had to be provided in the gear and in the capacity of the pontoons to insure freedom from breakdown at the final operation of unwatering the pontoons. Account had to be taken of the fact that the stresses coming on the apparatus would be violent and sudden at times.

(*b*) A plan had to be followed which would reduce the underwater work to a minimum, and which would not unnecessarily endanger the lives of the divers. These considerations ruled out any method calling for actual connection of the lifting chains to the hull of the vessel. It also ruled out making shackle connections to the pontoons. Any attempt to make such connections would have been dangerous and probably altogether impracticable, as the divers would either have had to work between the submarine and the pontoons, or under the pontoons, while these were suspended from above and were consequently pumping up and down in the swell. This consideration led to the use of chains, which were merely rove under the boat and brought up through hawse pipes in the pontoons. The divers were therefore able to work in comparative safety on top of the pontoons while attaching the clamps to the chains as described below.

(*c*) It was necessary to provide means for reeving the chains under the boat with accuracy in predetermined locations, and it was also necessary to land the cylinders within a few feet of their lifting positions. This required the use of a flexibly moored wrecking barge over the submarine.

(*d*) The entire plan had to be based on the proposition of completing the work

on and under the water with the greatest expedition possible once it was started, because of the danger of being overtaken by heavy seas at any moment. It was particularly important that once the first pontoon was landed there should be no delay, because a heavy swell would probably have wrecked the pontoons against the sides of the vessel.

DESCRIPTION OF PONTOONS.

Four of the pontoons, the bow and stern pairs, were made 32 feet long by 11 feet in diameter. The other two were made the same length but were 12 feet 6 inches in diameter. The buoyancy—that is, the lifting capacity—of the 11-foot cylinders was 63 tons, and, of the larger cylinders, 84 tons. The combined lifting capacity of the four pontoons was 420 tons. This provided excess capacity of 160 tons over the estimated weight of the submarine. Not only did this margin insure the necessary pull which might be needed to start the vessel, but it also provided for any failure to realize all the buoyancy available which would result should any of the cylinders become cockbilled to such an extent as to make it impossible to unwater them completely. It was correctly assumed that the full lifting capacity of the cylinders could probably not be developed, due to this cause. The weights of the cylinders were 63,000 pounds and 73,000 pounds respectively. The pontoons and their collateral equipment are shown on plans reproduced as Plates 14 and 15.

Securing the pontoons to the submarine was one of the most important features of the salvage arrangements. The plan adopted was very simple and proved entirely successful. Chains were rove under the vessel and, while the pontoons were afloat, were brought up through the hawse pipes already mentioned. These hawse pipes were 12 inches in diameter fitted 8 feet from each end of the cylinders. They were built up of steel castings connected by 12-inch pipes. After the pontoons had been landed on the bottom, cast steel clamps were bolted around the chains just above the hawse pipes. The clamps were made in halves molded to the shape of the links. The two halves were drawn together and kept from spreading by four heavy bolts. The clamps were of such length that they bridged the hawse pipes and therefore could not slip through when loaded. Fig. 3, Plate 5, shows a clamp attached to one of the chains. The details of this feature are also shown in Plate 15.

Fifteen-pound plating was used for the shell of the pontoons. The frames, consisting of 5-inch by 3-inch angles, were spaced 2 feet apart with web frames in the wake of the hawse pipes. Fore-and-aft girders of 12½-pound plating were fitted 90 degrees apart. These girders and the web frames were riveted to the lugs of the hawse-pipe castings, thus providing a very substantial construction for the support of the large concentrated loads at these points.

A transverse watertight bulkhead was fitted at mid-length dividing the pontoons into two compartments so as to facilitate sinking and blowing out. Without this bulkhead the cylinders would have been difficult to handle while being lowered into place, as there would have been no way of adjusting the trim. Two tons of con-

crete ballast was placed in the bottom of each so as to provide a certain amount of pendulum stability, otherwise they would have rolled too freely. A 4-inch flooding and discharge valve was fitted at the bottom of the end bulkhead of each compartment. Operating rods were provided for manipulating these valves from on top of the pontoons. A ¾-inch valve was fitted for each compartment, close to the middle bulkhead, for venting and for attaching the blowing-out hose. These valves were located in this position so as to keep them clear of the lines and the chains.

The outside of the pontoons was sheathed with Douglas fir 4 inches thick, applied in widths of 3 inches. The use of narrow widths made it unnecessary to work the planks to the curvature of the cylinders. The sheathing was not attached directly to the plating, but was held in place by ½-inch galvanized wire rope. The object of the sheathing was to prevent local damage to the plating in case the cylinders happened to land on anything sharp. The sheathing also served as chafing gear between the pontoons. The value of this feature was fully demonstrated in the actual salvage operations. In the case of all of the pontoons the wood on the side towards the submarine was so badly abraded that it is safe to say that the cylinders would have sprung leaks and possibly would have been punctured if this safeguard had not been applied. The object in not attaching the planking directly to the shell plating was to eliminate the danger of pulling out or loosening the bolts. A leaky bolt would have been as disastrous to the success of the undertaking as a puncture in the shell plating. The sheathing was fitted in four lengths, each section being held in place by three wire-rope straps. A plank runway was fitted on top of the pontoons so as to afford the divers a level platform to stand on while placing the clamps.

The valves in the end bulkheads were protected by heavy timbers. These timbers also served as fenders for the ends of the pontoons. The valve operating rods and end timbers were not placed vertically. This was necessary in order to clear the pads at the upper ends of the bulkheads. Three pads were fitted at each end. The side pads were intended for lashing across from one cylinder to its mate on the other side of the submarine. Such lashings were necessary only while the cylinders were resting on the bottom, in order to keep them snugly in position.

Figs. 4, 5 and 6, Plates 5 and 6, show the pontoons in various stages of construction.

One of the essential requirements of the plan of operations was that the lifting chains and pontoons should be placed accurately in predetermined positions with regard to the submarine. This called for mooring the salvage craft, which was used as the working base, to four buoys with control for shifting in any direction desired. Four wooden mooring buoys 10 feet 6 inches square were built for this purpose. These buoys were anchored 45 degrees off the port and starboard bow, and 45 degrees off the stern of the submarine.

The salvage craft consisted of a wrecking barge, which had formerly been a dipper dredge. This barge was 98 feet long by 35 feet beam. It was equipped

with a heavy "A" frame and a substantial boom. The hoisting machinery on the barge consisted of two engines, each having two drums of ¾-inch plow steel wire rope. By taking the mooring lines to the niggerheads of the engines, the barge could be shifted conveniently. Special lead blocks and sheaves were rigged for handling the chains and for lowering the pontoons.

For the bow and stern pontoons 2-inch chain was used. As the lifting capacity of the middle pontoons was considerably greater, 2⅝-inch chain was used for the latter. All six chains were rove under the boat before any of the pontoons were placed. Divers had to tunnel under the vessel to place several of the chains, but otherwise the work was accomplished without much difficulty by means of the special rigging provided on the wrecking barge.

PLACING THE PONTOONS.

After all the chains had been laid out on the bottom under the vessel the barge was shifted for landing the midship pontoons. These were flooded to about 3 feet of freeboard in the harbor before being towed out to the job. One pontoon was placed on each side of the barge opposite the "A" frame, as shown in Fig. 8, Plate 7. The four runners from the engine drums were dropped through the hawse pipes to the bottom and a report made by the divers on their location with reference to the chains. When the position was reported as satisfactory, the runners were shackled to the ends of the chains. In the meantime flooding the pontoons was continued.

A 50-foot length of pneumatic hose, fitted with a ¾-inch valve at the end, was connected to each vent. By manipulating these valves the trim of the pontoons was kept under control. The flooding valves were left open. As soon as the runners had been dropped through the hawse pipes and shackled on below, the clamps were placed on top of the castings, as shown in Fig. 9, Plate 8. In order to facilitate the work of the divers in bringing the two halves of the clamps together, loosely fitting ¾-inch guide bolts were passed through holes provided for that purpose in the ends of the clamp castings. These bolts were long enough to permit spreading the clamps to the full 12-inch diameter of the hawse pipes. The clamps were lashed to the running boards of the pontoons to keep them from slipping off.

Five-inch manila lines were made fast to the end pads of the cylinders. The forward line of each pontoon was taken to a timber head and the after line to the niggerhead of one of the hoisting engines. These lines were marked every 5 feet as a guide for lowering the two ends uniformly.

When everything was in readiness, the final flooding of one of the pontoons was started. As soon as the pontoons showed a tendency to sink, the vents were shut off to avoid further increase in negative buoyancy. Any slight excess of water in one compartment had the effect of making that end go down first and cockbilling the pontoon. The object of the lowering lines was to prevent the cylinders from sinking end on, as would invariably have happened without such control. As soon as the divers reported that a cylinder was lying squarely on the bottom, parallel

and close to the submarine, the vents were opened for complete flooding. In the case of one pontoon one end had to be lifted and swung in closer to the vessel. This would have been difficult had the pontoon been completely filled with water before the adjustment was attempted. The flooding valves were closed after the pontoons had filled completely, in order to prevent the entrance of sand.

Although the negative buoyancy was kept well in hand by careful venting, the cylinders, nevertheless, showed a decided tendency to become unmanageable and heavy as soon as the water plane area had vanished. All of the pontoons were, however, lowered without mishap and without parting lines.

The divers began bolting on the clamps as soon as the position of a cylinder was reported as satisfactory. It was not essential that the clamps for the first lowered pontoon of a pair should be fitted to any particular link, but, once fitted, it was necessary to know exactly the link on which each was placed so that the clamps on the opposite side might be placed correctly, this in order to insure that the proposed amount of slack was left in each chain. If the chains had been hauled up snugly and the clamps had been placed directly above the hawse pipes, the pontoons would have been held down alongside the submarine on becoming buoyant. This would have brought a considerable crushing stress on the sides and would have been particularly objectionable, because of the excessive stress to which the chains would have been subjected.

UNWATERING THE PONTOONS.

After considering various methods of unwatering the pontoons, the use of compressed air taken from torpedo air flasks was decided upon as the simplest and most reliable method. Calculations indicated that 20 torpedo air flasks blown down from 2,150 pounds to 200 pounds pressure would furnish enough air to raise the vessel. In order to maintain a rapid flow of air from the flasks it was proposed to blow down to only 200 pounds. Tests were made which demonstrated that a flask could be blown safely from 2,150 to 200 pounds pressure in about five minutes against a receiver pressure of 50 pounds. A test was also made on the flow of air through a 150-foot length of ¾-inch hose, using a differential pressure of 25 pounds per square inch. From this test it was found that the flow was considerably greater than given either by Halsey's or Kent's formulæ. On the basis that the air would be delivered to the pontoons by twelve 150-foot lengths of ¾-inch hose against a water head of 46 feet and with a differential pressure of 20 pounds, it was calculated that the cylinders could be unwatered in about 100 minutes. When this stage of the work was actually reached, the differential pressure was kept somewhat below 20 pounds as a precaution against starting the seams of the end bulkheads of the pontoons. The cylinders were actually unwatered in about two hours after air was fully turned on.

Twenty-four torpedo air flasks were installed on a coal barge, as shown in Fig. 10, Plate 8. These flasks were connected in parallel to a 7-inch extra-heavy pipe. This pipe discharged into an expansion chamber made from a piece of cast-iron pipe

22 inches in diameter by 8 feet long. The expansion chamber was piped to a 12-valve manifold, to which the pneumatic hose lines leading to the pontoons were attached, as shown in Fig. 11, Plate 9. A gauge was installed on the 7-inch pipe, as well as on the valve manifold.

The 7-inch extra-heavy pipe was necessary so that if any one of the valves from the flasks should happen to blow through, the full pressure would not be thrown on the large expansion chamber and on the hose leads. This arrangement also made it possible to throw in a new flask by simply opening a valve. The pressure at the hose manifold was kept at 35 pounds until the cylinders emerged. By throttling the flask valve and the valve in the line to the expansion chamber, this pressure was maintained without difficulty.

FINAL SALVAGE OPERATIONS.

The work of passing the chains under the vessel was not started until the pontoons and all of the collateral equipment needed had been made ready. It took three working days to place the chains, with a few intervening days when the swell and under-tow were so heavy that divers could not stay on the bottom. The three pairs of pontoons were placed on three successive days. The job of substituting the coal lighter, with its equipment of air flasks, for the wrecking barge was completed on Saturday, August 28, too late to unwater the pontoons on that date. This work could not be done with certainty at night.

Fortunately the weather held good through the night. The final work of connecting up the hose leads to the pontoons and opening the discharge and blow valves was started at daybreak on Sunday, August 29, 1915. This work was left until the morning, as it would have been inadvisable to subject the twelve 150-foot lengths of hose to the action of the swell during the night.

When all necessary preparations had been made, a diver was sent down to watch the pontoons and to report by telephone as they became buoyant. The air was first started on all four compartments of the stern pontoons. When this pair was buoyant the air was shut off and the middle pontoons were started off the bottom in the same manner. In the case of the bow pontoons it was necessary to bring the forward end of the seaward cylinder off the bottom in advance of the after end in order to clear the bow rudder on this side, which was still in place and projected upward at an angle of about 45 degrees. If this precaution had not been taken the pontoon would have jambed against the sharp point of the rudder and would probably have sprung a leak. The pontoons were all partly unwatered before turning on the air to all six cylinders, in order to make certain that all the lines and discharge valves were functioning properly.

When the pontoons had in turn been brought to a reasonably horizontal position by manipulating the manifold valves, air was turned on to all twelve compartments. One end of the submarine came up slightly ahead of the other, as was inevitable. In Fig. 12, Plate 9, the bow pontoons are shown just emerging. It will be

noted that one of the pontoons is still considerably cockbilled. This condition existed in the case of all of the pontoons until they had adjusted themselves on the surface, because the chains were rove under the vessel from the pontoon on one side to its mate on the other side without being attached to the submarine. One end of each pontoon was bound to become buoyant slightly ahead of the other, also the two pontoons of a pair could not be manipulated so as to bring them buoyant simultaneously. As a small amount of slack was intentionally left in each chain, the pontoon which became buoyant first pulled the slack through under the vessel. This resulted in cockbilling the pontoons while they were completely submerged. So long as there was a sufficient amount of margin of buoyancy in all six pontoons the cockbilling was not of great importance, as enough water could be blown out of the high ends to provide the lift needed. The low ends could, of course, be completely unwatered. Once the pontoons emerged they immediately adjusted themselves automatically, as the high ends ceased to be water borne and therefore exerted no pull on the chain. This permitted the buoyancy of the low end of the opposite pontoon to assert itself, thus causing the chain to render.

Fig. 13, Plate 10, shows the pontoons on the surface ready to be towed into the harbor, with their suspended load. It will be noted from this cut, as well as from Fig. 14, Plate 10, which shows all the pontoons more clearly, that they have adjusted themselves to practically a horizontal position.

DISCUSSION.

The President:—Discussion on the paper which has just been read, entitled "Salvage Equipment Used in Raising Submarine F-4," is now in order. Is there any member or visitor who desires to discuss this paper?

Captain A. P. Niblack, *Vice-President*:—In connection with this very interesting paper, there is one phase of the salvage of submarines which is rather interesting to touch upon, and that is, in a good many other navies they have provided special types of salvage vessels that are intended to be used in case of accident, but our Navy has, for various reasons, not followed this custom. The reason is probably very much on account of the extent of our coast line and the wide distribution of our submarine bases.

There is now in session a board of naval officers to locate bases for submarines and aircraft in our various possessions, and the question, I should think, would then come up of submarine salvage vessels; in other words, the operations of the submarine have been heretofore rather scattered, and not particularly organized and directed from definite centers. I simply allude to this fact because the design of salvage vessels has been one of very great interest, and there have been various types developed, in which naval architects all over the world have been in competition.

The author of this paper has called attention to the splendid service of the divers. It seems to me the problem of raising the F-4 practically hinged upon the wonderful diving

which was done upon that occasion by those men who have vindicated and demonstrated the efficiency of the naval diving school at the Torpedo Station at Newport, R. I., which we have maintained for so many years.

Naval Constructor Furer:—As there seems some time left, possibly a few remarks on Captain Niblack's comments on submarine salvage vessels may be of interest.

Our experience in salving the F-4 leads me to the conclusion that salvage vessels are not a good investment. If a salvage vessel had been available in Honolulu at the time of the F-4 catastrophe, the raising of the submarine might have been simplified to some extent, but the presence of such a vessel would not have made it possible to save the crew in any case, because it is probable that all hands perished within fifteen minutes after the accident happened; that is, long before it was even known that the vessel had met with an accident. The main problem was to get lifting cables under the vessel. In this a salvage vessel would have been of little help. The secondary problem was to provide the mechanical means for lifting the submarine. It is conceivable that a submarine lying disabled in shallow water might be brought to the surface by a salvage vessel in time to save the crew, but to make this possible all the conditions would have to be very favorable. In the first place, lifting attachments would have to be provided on all submarines corresponding to the lifting arrangements of the salvage vessel. Such lifting attachments would have to be rugged and of generous proportions so as to take care of the large stresses involved and so as to make speedy connection with the lifting tackle possible. This would mean a considerable increase in the hull weight of submarines, which would serve no purpose except the remote contingency of possible use in case of accident.

If, on the other hand, no special arrangements were provided for quickly hooking on the lifting gear, and if cables had to be worked under the submarine any way, the possibility of saving the crew would vanish because of the length of time required to perform this operation. If, then, the salvage job is merely one of bringing the vessel up sooner or later to determine the cause of the accident and to recover the bodies of the crew, as it was in the case of the F-4, it is much more economical to provide such special means as may be indicated by the particular nature of the job, even if more time is required. It is probable that no two jobs could be treated in exactly the same way. The surrounding conditions will always vary to a considerable extent and will call for special solution of each problem.

Then, too, if salvage vessels were provided it would be necessary to have at least five such craft to insure the presence of one in each general locality where our submarines operate. This investment would be enormous as compared to the cost of an occasional salvage job necessitating the purchase or manufacture of special equipment. The entire cost of salving the F-4 was about $125,000, represented largely by the cost of the special windlasses and special pontoons provided for this purpose. This gear is still available should it be needed in the future.

Captain Niblack referred also to the training of the divers. Several years ago the Bureau of Construction and Repair took up the investigation of deep-sea diving and conducted extensive tests at the New York yard to determine the factors which differentiate this kind of work from usual shallow-water work. The best means of providing air to the divers, the problem of proper telephone equipment, and the details of the type of recompression chamber needed to make deep-sea diving practicable, were investigated. It so happened that the experimental work was brought to successful termination by the Bureau of Construction and Repair shortly before the accident to the F-4. The men who had been trained, and

the medical officer who had conducted the physiological investigation in connection with the tank experiments, were available and were sent to Honolulu on this job together with the equipment which had been developed at the New York yard.

From the success of the diving operations at Honolulu the bureau felt that the methods used were out of the experimental stage, and the equipment has accordingly been transferred to the Torpedo Station, Newport, where other divers are now being trained for deep-sea work.

THE PRESIDENT:—What was the record for deep-sea diving prior to this particular case?

NAVAL CONSTRUCTOR FURER:—In connection with the research work conducted at the New York yard, two of the men went down to a depth of over 200 feet off New London. These dives were in the nature of tests to check up the experimental work which was being done at the New York yard. I believe that the record for actual deep-sea work was made off the Grand Canaries some years ago by a diver who was engaged in recovering the treasure from a Spanish galleon. This diver worked at a depth of 167 feet and recovered about $200,000 worth of treasure. He finally broke down under the work and became completely paralyzed. No decompression methods were used, which no doubt accounts for the physical impairment of this man.

THE PRESIDENT:—The men in the case of the F-4 remained under water for 10 or 15 minutes?

NAVAL CONSTRUCTOR FURER:—When the vessel was lying in 300 feet of water, they were not intentionally kept on the bottom more than fifteen minutes. On one occasion a diver got foul of the life-line and air hose when at a depth of about 200 feet. A second diver had to be sent down to clear the line and hose. The first man had to remain at approximately this depth for about two hours. He came up in very bad condition. His life was at first despaired of, as he contracted double pneumonia, which is one of the results of prolonged exposure under great pressure. He finally recovered, however.

THE PRESIDENT:—Is that man all right today?

NAVAL CONSTRUCTOR FURER:—Yes, he recovered entirely, and is, I believe, in normal health today.

THE PRESIDENT:—Is there any other gentleman who wishes to discuss this paper? If not, I wish to congratulate Mr. Furer on the success of his enterprise which he has described so minutely and well in this paper, and I wish to extend to him the thanks of the Society for the care he has taken in the treatment and presentation of the subject, and in giving it to us for our records.

We will now take up paper No. 3, entitled, "The Design of an Oil Engine," by Mr. John F. Wentworth, Member.

Mr. Wentworth presented the paper.

THE DESIGN OF AN OIL ENGINE.

By John F. Wentworth, Esq., Member.

[Read at the twenty-fourth general meeting of the Society of Naval Architects and Marine Engineers, held in New York, November 16 and 17, 1916.]

The actual design presented here was made to fit the needs of the submarine —a light and reliable type of engine. If we were to consider a design suitable for a freighter, the matter of weight would not be so important, but the matter of reliability and low upkeep would be more important. The attempt has been made in presenting this design to give data and substantiating reasons for opinions where perhaps satisfactory data cannot be presented, so that this paper may be taken as a basis and, if desired, other designs may be worked up in any well-organized draughting office.

In designing an engine there are several points to be settled upon as a matter of policy; from this point the design is not peculiar to the oil engine but rather is a straight matter of mechanical design. For instance, it has been suggested that the matter of bearing pressures is something to be settled by oil-engine experience. The opposite viewpoint is taken. It is felt that the bearing pressure in the oil engine should follow the same laws that are followed in other machines of somewhat similar action. For instance, we find the bearing pressure allowed in a locomotive is higher than that allowed in a triple-expansion steam engine. The reason is very easy to understand. In the locomotive the maximum pressure lasts for but a short part of the stroke, especially in single-expansion locomotives. On the other hand, in the compound marine engine the cut-offs are late and the maximum pressures extend over a much longer part of the stroke. Since the limiting point is the heating of the bearings, and since a machine which has an intermittent action has a greater time to dispose of the heat generated by the pressure, the maximum pressure per square inch may run higher. Engineering science has many examples of how this works out in practice, and it would seem that such question need not be of great moment to an organization skilled in machine design. This point is mentioned so that it may be understood that, in some, if not in many instances, data from work quite dissimilar to the design of the oil engine have been used. In such cases the application of the force is similar, even though the resulting design may differ very much from the completed oil engine.

The next point in a general consideration of the problem is the actual experimental data which already have been presented on this type of engine in the paper on "The Thermodynamics of the Marine Oil Engine" published in the Transactions of 1914.

The third point consists in following certain deductions derived from experi-

mental data and from a theoretical consideration of points in the design as affected by this experimental data.

If these three assumptions are justifiable, there should be no hesitation on the part of a well-organized engine-designing force to undertake the design of an oil engine to fill a certain requirement. Attempt has been made to emphasize this matter strongly. Experience is a wonderful guide, and the author would be the last to decry its value. However, it seems, in view of the newness of the oil engine as a commercial machine, and in view of the fact that all who are interested in this matter are too apt to be partisan advocates of one type or another, that an engine designed under this method might offer advantages which the product of some exploiting firm would lack. It is not claimed that the author is an impartial person. Quite the reverse is true. But it is hoped that this paper may be considered from an engineering viewpoint, each one having the privilege of rejecting those points which reflect the enthusiasm of the author or, rather, of making such allowance for these individual ideas as may seem wise and of considering how the paper as a whole may be used as a guide for such designs. It will be a long time before these matters of type are settled to the satisfaction of all. For this reason it is perfectly proper for the author to present his individual opinions, believing them to be best. At the same time this paper does not depend upon these theories, but is rather an attempt to handle the whole matter on such a basis that changes in this design to eliminate these individual theories would not affect the work of handling the new design in the draughting room. It would simply mean new allowances for changes in method of operation in the engine.

Under the head of general data there are several points to be settled before the design is begun. They are at present largely a matter of judgment. There are apparent reasons for following certain designs. These will be given as they appear to the author. Owing to the newness of the oil engine these claims of supremacy cannot be positively stated as facts, but good reasons can be given for their adoption.

The general features to be decided upon before the actual design is begun are as follows:—

1. The type, whether two-cycle or four-cycle.
2. The pressure of compression, and whether this pressure shall be constant or not.
3. The class of fuel to be used, and what steps shall be taken to insure its successful use.
4. The means for starting, and what, if any, steps are needed to make practical the particular type of starting settled upon.
5. The best arrangement of the air compressor.
6. The peculiar qualities necessary in fuel valve and fuel pump.

TYPE.

The type selected was four-cycle and the engine designed for naval use. The Navy needs two speeds; one is a normal economical cruising speed and the other a maximum possible speed, regardless of economy.

The four-cycle is unquestionably superior to the two-cycle because it allows a greater variation. In a four-cycle engine by a simple matter of admission valve control any desired pressure of compression can be obtained. This is possible in the two-cycle only by making the normal pressure the low pressure. In other words in the two-cycle the pressure of compression can be varied only by increasing the pressure of the scavenging air. Any regulation of the pressure by a reduction of the scavenging air below the normal would seem to be very difficult to obtain, that is, the normal compression should be that pressure which would result from having a full cylinder of air at atmospheric pressure. It is quite difficult to see how any pressure lower than this is practical in the two-cycle engine. A higher pressure than this can be obtained by increasing the pressure of the scavenging air.

In the condition of the engine today there are many points which will remain a matter of opinion till settled by exhaustive tests. With a four-cycle engine these points in some instances can be settled by the use of such a type of valve action that the same engine can be run on different cycles or types of indicator cards. From such tests much valuable data could be obtained, and so, if for no other reason, it seems wise to adopt the four-cycle type.

Even the most ardent enthusiasts for the two-cycle type do not claim it comes nearer than nine-tenths of the efficiency of the four-cycle type.

Also the matter of simplicity must be considered. Is it simpler to have a given number of cylinders with a more elaborate system of valves in the head or is it better to increase the number of cylinders by adding scavenging cylinders? The author holds that the four-cycle type is the more simple.

Notwithstanding this opinion, considerable attention has been given to the two-cycle type in order to make as many of the author's theories applicable to the two-cycle as is possible. It is hard to see how the weight of the four-cycle type can be reduced by making a two-cycle, and it seems that the simplicity of valve gear is more than offset by complications in the engine as a whole, and also that a great amount of flexibility is sacrificed by adopting the two-cycle type.

COMPRESSION.

Notwithstanding Diesel's theory, the compression pressure in the oil engine is primarily carried to the high point for the purpose of producing a temperature of ignition. The designer should consider this feature very carefully to see if a lower pressure cannot be used with better results.

We know that a pressure of compression of about 500 pounds will give a temperature sufficient to ignite the fuel spray. If this pressure can be reduced, the result will be lower-bearing pressures and reduced strains in the crank shafts. Since this means a lighter and more durable engine, it becomes of vital interest to know just how low a pressure of compression can be used. It has been fixed that from 450 to 500 pounds will be an average figure to use for the conventional type of engine. This pressure can be very greatly reduced by warming the cylinders, by steam for instance, before attempting to start the engine. The estimated pressure of compression will not vary from the actual pressure by any considerable amount.

We know that a small four-cycle oil engine, when warm, will fire on a compression of 125 pounds. It is certain that under the same conditions—namely, after the engine has been warmed up by operation—the larger sizes will be able to run on pressures as low as 150 to 175 pounds.

This latitude may be objected to as being altogether too great to be tolerated in a design which is to be built. Just as the main bearings have to be scraped to fit the shaft, so it is possible to fit the cylinders with a proper clearance. This is not a very difficult matter; that is, in case of an error in estimate, no parts need be scrapped. There are several ways in which considerable adjustment can be made in the cylinder clearances. In the original engines put out by the American and British Manufacturing Company, the shaft was raised or lowered by means of wedges upon which the bearings rested. This seems to offer a little too much chance for meddling on the part of irresponsible parties, and it is suggested that the connecting rods may be lengthened or shortened to make the needed variation. In addition to this method, it is possible to get the same result by taking a chip from either the head or the cylinder, or a slightly thicker gasket might be used in place of the original gasket. Even this change in the gasket might be objected to, while absolutely no objection can be found to taking a chip from the head or the cylinder in case the engine is found to have too great a clearance and in case the clearance be not large enough to taking a chip from the connecting rod. In fact, with a marine type connecting rod, all the variation which is necessary can be made by either lengthening or shortening the rod. This matter of adjustment will not be a serious one, and when the designer understands that his estimated clearance can easily be altered, in case of need, without the waste of any machined parts, greater confidence should exist in his mind in regard to the final product. Having shown how the clearance can easily be altered to suit the needs of the engine, the necessity of wide experience is done away with.

The clearance will vary for the different types to be built. For instance, a small high-speed engine will run on a lower compression since the length of time is a minimum during which the compressed air at its maximum temperature is exposed to radiation losses under the worst condition. On the other hand, in a large and slow-speed engine, while the air at the end of the stroke has a longer time in which to lose sufficient heat to prevent ignition, the space in which the air is compressed is much greater and hence the facilities for heat losses are less. It is very probable that there will not be a very great difference in the clearance which can be used. The time element in the high-speed engine is to a very great degree counteracted by the increased clearance of the larger engine.

INITIAL TEMPERATURE OF THE CYLINDER.

The data presented in "The Thermodynamics of the Marine Oil Engine" prove conclusively that the full pressure of compression is not needed after the engine has been run long enough to get warmed up. Since the engine will warm up in a

very short time under the fuel cycle, obviously it is important to decide how to bring the engine to a condition of design under which it will not only start but, after starting, will be in the most ideal condition for operation under the fuel cycle. The engine built in large units must be jacketed when running on the fuel cycle. Vessels of any considerable displacement must have steam aboard for auxiliary purposes. Under these circumstances the most practical means for meeting this condition is to provide the water jackets with steam pipes, so that steam can be admitted to the cylinder jackets in order to warm the cylinders preparatory to the first explosion. The term "explosion" is used here with a purpose. Combustion and explosion differ chiefly in the time element. The explosion we usually associate with a rising pressure, and it is this rising pressure which is needed in the oil engine. By using steam to heat the cylinders it is possible to produce a card such as is shown on Fig. 1, Plate 16, marked "Ideal Card of the Low-Pressure Type." It is only after the engine cylinders have been warmed in some manner that such a card is possible at the initial stroke. Since only a small amount of steam will be needed to warm the cylinders, it seems highly desirable to install a steam plant for this purpose, even if there be no other use for steam on the vessel.

EFFECT ON THE EFFICIENCY OF THE ENGINE.

The ultimate efficiency of the engine is a combination of the thermal and mechanical efficiencies. The thermal efficiency depends upon the number of expansions. The mechanical efficiency depends upon the ratio of the mean effective pressure to the average pressure during the compression and expansion strokes.

It was explained in the Transactions for 1914 how the thermal efficiency was not reduced by reducing the pressure of compression and increasing the clearance while advancing the fuel injection. Fig. 1, Plate 17, shows two cylinders of the same size, but one is of the low-pressure type and the other of the high-pressure type. Besides the expansions there is the matter of radiation. The greater the clearance the less chance for radiation loss. Fig. 2, Plate 16, contains some comparisons to bring this out. Here we see that while the volume of the clearance of the Diesel or high-pressure type is but .30 of the same volume for the low-pressure type, the surface of the Diesel clearance is about .78 of the surface of the low-pressure type. This shows how the opportunity for radiation losses is much greater in the high-pressure type.

Before considering the mechanical efficiency it is quite important to understand the effect produced upon the power by the reduced compression. Referring again to Fig. 1, Plate 17, we find the relative volumes of air compressed per stroke in the two types of engines. For convenience the two engines were taken as each being 12 inches bore and 12 inches stroke. It is suggested as desirable to place a blower on the intake pipe in order to improve the scavenging. Assuming perfect scavenging, the volume in the low-pressure type at the end of the suction stroke will be .91 cubic foot against a corresponding volume of .85 cubic foot for the high-pressure type owing to the fact that the low-pressure type has a greater clearance.

In order to be a commercial success th oil engine must not only have the efficiency but also the power. This point is a strong one in favor of the low-pressure type. The full overload condition of the engine means that the maximum amount of fuel must be used. The maximum amount of fuel depends upon the amount of air which can be compressed per stroke. Here we have about 7 per cent more air in the cylinder of the low-pressure type than in the high-pressure type of the same bore and stroke. It is obvious that the amount of fuel which we can use will be 7 per cent greater in the low-pressure than in the high-pressure type. Against this argument it can be said that in order to produce the same ignition temperature in the low-pressure type as is produced in the high-pressure type, the air in the low-pressure type must be hotter than is the case with the high-pressure type and hence the weight of air will thus be reduced. This argument is a good one and must be considered. The answer is that in the high-pressure type the air is cooler than in the low-pressure type only in the beginning of the operation of the engine. It has been shown how, as the high-pressure type is warmed up, the air at the beginning of compression is much above the normal room or atmospheric temperature and the final temperature at the end of compression is much above that needed for ignition of the fuel. For this reason the comparison by weight of the air compressed in the two types of engines will not vary appreciably from the comparison by volume. This being so, the amount of fuel used per stroke in the low-pressure type will be about 7 per cent more than is possible in the high compared on a basis of piston displacement.

The mechanical efficiency of the engine is the ratio of the brake horse-power over the indicated horse-power. The brake horse-power is the indicated horse-power minus the frictional loss. The frictional loss is a function of the pressure on the bearings and also certain losses in the auxiliaries. As far as the bearing losses are concerned or the main-engine friction, this is largely a function of the sum of the average pressure for the compression as well as for the expansion strokes. Without going into a detailed calculation it is evident that the sum of these two average pressures will be less in the low-pressure type than in the high.

For this reason it would appear that the low-pressure type has a greater power for the same piston displacement with an equal thermal efficiency and a greater mechanical efficiency. This seems to be the ideal condition sought for in the oil engine. It means a more powerful engine and at the same time reduced bearing pressures and stresses which will be reason for expecting a longer life and reduced upkeep.

Here is the proper place to take up the matter of the injection air. In the high-pressure type of engine about 10 per cent of the net brake horse-power is consumed in the air compressor. Since the pressures are lower in the low-pressure type, the air for injection purposes can be reduced in pressure, which will reduce the loss in the air compressor, which in turn will give an additional gain in the efficiency of this type of engine.

Plate 20 shows graphically the manner in which the low-pressure engine will

gain on the present type of high-pressure engine. In Fig. 1 we have three typical indicator cards. Card *A* is a conventional Diesel card taken at full load. Cards *B* and *C* are ideal cards. The reason for expecting that such cards might be produced will be found in the sample cards shown in the paper on "The Thermodynamics of the Marine Oil Engine," Transactions of 1914. These cards gave combustion lines as shown. The height of these cards or the total power is estimated by allowing for the increase of air present over the Diesel card. It is of course reasonable to assume that for a given bore and stroke the amount of oil per unit of air can be kept constant and hence, as the air increases by weight the weight of fuel can be increased, and hence the power will be increased per unit of piston displacement. This has already been taken up.

These three cards were developed as shown in Fig. 2, allowing a constant ratio of crank to connecting rod for all three cases. The pressure in the cylinder for every 20 degrees of crank angle was obtained for the three cases. With this data the three curves were drawn in as shown. It is evident to the eye that the average pressure for the combined compression and expansion strokes is greatest in the Diesel Card *A*. Now the mean effective pressures of these three cards have been figured and are 113, 128 and 140 for *A, B* and *C* respectively. If we plot the average pressures obtained from Fig. 2 and the mean effective pressures on the respective clearances of the three cards, as has been done in Fig. 1, we see how the power increases as the clearance increases and how the bearing pressures will fall off.

This shows that by a variation in the direction of an increase in clearance the stresses in the engine will decrease, the power will increase, and bearing troubles will decrease. It is very seldom that in the solution of a commercial problem we have three variables which are all benefited by the change of a single factor as is shown to be the case here.

SPEED VARIATION.

For the marine engine, and especially for the naval engine, this is a most important feature. It is here that admission valve control comes in. In all present oil engines the speed is controlled by a variation of the fuel fed per stroke. This means that at reduced power the engine compresses an unnecessarily large amount of air per stroke. Unnecessary work means mechanical loss. For this reason it is proposed to reduce the amount of air compressed per stroke as we reduce the amount of fuel used per stroke. Under the Diesel school theories this is impossible. It has, however, been proven possible to a certain degree by the experiments of the author. The result is that no unnecessary frictional loss is occasioned by the compression of an unnecessarily large amount of air.

There is a theoretical gain in the low-power cycle which is independent of the mechanical gain. In the internal-combustion engine the pressure at the opening of the exhaust passages is still very high—from 20 to 30 pounds. Suppose we could collect this high-pressure working fluid and expand it in a secondary cylinder

without loss from back pressure. This would result in an additional saving of a very considerable amount. On the proposed cycle this is accomplished. Let us assume that the admission valve is closed at two-thirds of the suction stroke. Then when two-thirds of the expansion stroke is completed a normal cycle is closed. On the low-power cycle the expansion is continued 50 per cent further before the charge is exhausted. In this way the efficiency of the low-power cycle is greatly increased.

Besides this condition of economical low speed there comes the condition of extreme low speed which is only occasionally needed. Here economy is not a factor. The engine must run slow regardless of economy. The limit in low speed comes from the loss of ignition temperature due to radiation. This can be overcome to a degree by controlling the circulation of the cooling water. As the engine slows down the work done per stroke is reduced and consequently the heat which must be carried off is reduced. So far as is known the author is the first student of the internal-combustion engine to suggest attaining a lower speed through a regulation of the temperature of the cooling water. This seems, however, to be important. There will never be a call for a prolonged operation at extreme low speed. In such cases as picking up a disabled ship at sea, or in similar emergencies, it is most important to be able to regulate the amount of cooling water fed to the jackets in order that the excessive radiation losses may be avoided. The means for accomplishing this result seem to be practical and to follow the commonly accepted laws of thermodynamics, which apply to the oil engine as well as to the steam plant.

FUELS.

This is a subject of utmost importance. The oil engine has come to stay, and as the number of engines increases the inevitable result will be a rise in the price of the available fuel. The oil-producing interests have so far met the oil engine rather more than half way. There are fuels on the market known as "Diesel engine oils." These fuels are, if the author is not misinformed, distillates, that is, the refuse from the production of lighter oils is heated to a temperature above that at which the kerosene is evaporated and the resulting vapor is condensed. This gives a fuel which is fairly fluid, and which in a way is a by-product. Gasoline was originally a by-product and, like gasoline a few years ago, this fuel is at present very reasonable in price. It is not safe or wise to depend upon this condition continuing. The oil engine is doomed to be extremely limited in its application if this fuel is depended upon.

The fact that this fuel is a volatile product like gasoline, although vaporizing at a much higher temperature, is of no importance to the oil engine. All that is needed for the oil engine is a free flowing fuel. Even the presence of a considerable amount of non-volatile matter like the asphaltum residue seems to be of no disadvantage in this type of engine. The one essential is that the fuel must be free flowing. In this one great point Dr. Diesel stood out pre-eminently ahead of his time.

He went so far as to propose the use of coal in a pulverized form in his engine. While the use of coal in the engine is of very doubtful value, the use of all grades of fuel oil is unquestionably practical. How to utilize these low-grade fuels is very important.

We buy fuel by bulk, and it is practically true that all fuel oils have the same calorific value. The point to be considered is that when a heavy fuel is bought by bulk, although the calorific value per pound is somewhat less than for a high-grade fuel, the calorific value per gallon is greater. Since we buy the fuel by the gallon this is what interests us.

Again, in order to protect the development of the engine against being checked by the rising price of the fuel oil, it is very essential to be able to use the same fuels as are used under the steam boilers. If this be done, since the oil engine has an efficiency of not far from three times that of the steam engine, the steam engine can be driven back to the use of coal before the oil engine can be seriously affected by the rise in the price of fuel.

Having shown the extreme desirability of the use of this low-grade fuel, next in order is the study of means for using it with good results. There seems to be one means which has already been proven in the steam plants, that is, to heat the slow-flowing fuels before feeding to the fuel pumps and fuel valves, and to do away with the jackets on the fuel valves while changing the design of the valves so that this can be done without serious trouble. As far as the operation of the engine is concerned, the heavy fuel, when thus treated, is in every way the equal of the gas oil. For this reason it becomes of the utmost importance that the treatment of the fuel, preparatory to spraying, be studied with the utmost care.

For all practical purposes it can be stated that the Baume of asphaltum base fuels will increase one degree for each increase of 15° F. in temperature. With this change in Baume there is also a change in viscosity. This change is needed to make extreme low grades of fuel oil available. It will not be sufficient to simply heat the fuel oil; it must be kept hot till after the oil spray is formed. This means that the water jacket must be omitted from the design of the fuel valve, a step which has already been adopted by some engine builders. The only excuse for a water jacket on the fuel valve is to prevent combustion in the fuel valve. This can be prevented by a change in the design of the fuel valve, and better results will be had from this new type of valve.

In suggesting anything new in an engineering line the reason must be looked for to explain why this has not been done before. It is not safe to say that a reason does exist. Only too often the new idea has never been tried on account of a lack of inventive or imaginative ability rather than on account of too great an understanding of the obstacles confronting the designer. In this case there seems to be no obstacle in the way of building a universal oil engine. By this term is meant an engine which will use all grades of fuel without changing any of the parts of the engine. For instance, it might be possible to design an engine with several interchangeable fuel valves, so that as the type of fuel was changed a suitable type of

valve would be available. This does not seem desirable or necessary. By controlling the application of heat to the fuel it seems very reasonable to believe that any grade of fuel will be satisfactory, and the only mechanical problem will be to design a fuel pump to handle the fuel and a fuel valve to produce the spray.

FUEL PUMP.

In his experimental engine the author had means for pumping up a fuel pressure, by moving the block, which carried the lower end of the pump connecting rod along a slide oscillated by an eccentric. When the engine was at rest, by moving this block from the position of no motion to the position of full stroke of the pump, a movement of the pump plunger was obtained. It was found that a slow motion of the plunger did not produce as good results as a very quick and sharp motion. This suggested that more ideal conditions could be obtained by designing a pump in which the fuel would be delivered by a blow on the plunger like that which would be given by the impact of a hammer. The only practical reason for this is that such a blow will start the check valves better. In a way the check valve is moved by the stream of fluid in the pipes, and the more rapid the motion of the fluid the more perfect is the action of the valves. No doubt the trouble which the author experienced was due to imperfect mechanical details, but if this modification will enable a more imperfect construction to produce the desired result it cannot be out of place in a perfect mechanical device.

Besides the advantage in the action of the check valves resulting from this design, there is a further gain. This gain is shown by the figures on Plate 19. In spraying a heavy oil from the present type of fuel valves considerable difficulty seems to be encountered from the fact that the fuel is delivered to a fuel-receiving chamber and then picked up from this chamber by means of the injection air. With a light fluid fuel this difficulty is not noticed. As the oil becomes more heavy and sluggish this difficulty increases. The sheet referred to explains the situation. In the first two figures the heavy black line shows the duration of the delivery stroke of the fuel pump. This would be for full stroke or the full-power condition. The short, light space at the top shows the duration of the opening of the fuel valve into the cylinder. From this it becomes at once evident that the fuel is delivered to the fuel valve and there comes to rest. From this position of rest it must be again put in motion and torn apart by the action of the injection air. There is a certain inertia to the oil and this inertia is greatly augmented in the case where the fuel has a high viscosity. This type of fuel valve is that proposed by Geo. B. Brayton and patented by him. In these figures the time of a complete cycle of the engine is shown by the full circle of 360 degrees. The various events of the cycle are shown in the figures. The next figure shows the method which is proposed by the author. As will be seen in the consideration of the fuel pump, the two strokes of the pump are of short duration and the rest of the time the pump is idle. The theory of this method of fuel injection is to co-ordinate the operation of the fuel valve and the

fuel pump so that the fuel valve will open, starting a stream of injection air into the cylinder, and at the same time the discharge from the fuel pump will take place, delivering the fuel charge directly into the stream of moving air where it will be broken up and delivered into the cylinder in the form of a suitable spray. By this method one of the obstacles to heavy fuel will be overcome. From the time the pump begins to deliver its charge the fuel will not be allowed to come to rest. In this way the fuel valve can be simplified in its design and the question of a delicate proportioning of parts to suit a special type of fuel will be done away with. It will be possible with a little experience to vary the pressure of the injection air, giving an additional saving. This, however, will be a matter of adjustment possible while the engine is in operation. Even if this be ignored, the gain through the use of heavy fuel, not practical in the present types of fuel-feeding arrangements, will be made without any counteracting loss. The fuel valve of this arrangement consists simply of two passages, each controlled by a separate needle valve. These valves are worked from one tappet rod and the air valve must be opened first, with the opening of the fuel valve being timed to the delivery of the fuel by the pump. In this way a stream of air will be started and the oil delivered into this air, and then the air will continue to flow for a short time after the delivery of the fuel in order to clean the passage to the cylinder so that the valve may not be clogged.

The fourth figure is an enlargement of the fuel and air delivery events. The duration of the opening of the valves and of the pump strokes can be controlled as well as the timing of those events. At first thought this seems to be quite a complication, but on closer observation this complication is shown to be nothing but what exists in every automobile engine. Certainly, if it is advisable to vary the timing of the spark on an automobile engine for the sake of speed control, it is not out of place to contemplate a similar modification in an expensive plant where the efficiency gain will be a great factor. Again we have several elements here. It would be impractical to have the elements all under individual control. It will be possible, however, to have a connection between the fuel-pump control and the fuel-valve control so that one lever will regulate all. This would be similar in idea to the present method of changing the cut-off on all cylinders of a compound steam engine from one lever, and at the same time with a provision for varying the cut-off of the separate cylinders at will.

STARTING.

This is the first thing to be done with the engine and has been the last to receive consideration. The reason is that the time under the starting cycle is very short, and the matter of efficiency is not worth considering. By efficiency is meant the thermal efficiency. It is a matter of efficiency whether the engine will start or not. It becomes a matter of efficiency if it be shown how the engine can be run for an appreciable time on the energy which can be stored in a compact form available for instantaneous use. This is a matter of practical utility rather than of thermal efficiency. That the matter of thermal efficiency does come into this consideration is only incidental.

The steam engine starts with an expansion stroke and has steam available for this stroke, so the starting feature is not a factor. In the internal-combustion engine the starting problem is a most difficult one. Not alone does the engine have to be accelerated but the acceleration has to impart sufficient energy to overcome inertia, do the work of the engine and at the same time produce the compression stroke.

Up to the present compressed air has been universally used for this purpose. The oil engine is still in its swaddling clothes and many developments must be worked out before the engine can take its place in the world's work as a tried and reliable element. For the generation of heat on shipboard the use of steam is practically essential. Then it is recognized that air starting is not absolutely reliable, for air must be generated. This may be done by a small oil engine. The auxiliary plant in turn must be started by air. This condition has brought about the use of a small steam-driven air compressor, or an electric air compressor, supplied with current from a turbo-generator set driven by steam. This is mentioned to show that even now it is realized that steam, either directly or indirectly, is the only reliable means for starting the oil engine. This being the case, why not abandon the use of air altogether and start directly from steam? This feature was taken up in the previous paper on the oil engine, but not in detail. The data on Plate 18 are presented to show the advantage in the use of steam. The effective energy in one cubic foot of water at a steam pressure of 200 pounds and of air at a pressure of 500 pounds are compared, as well as the cost of producing this energy. This cost is a matter of small importance. However, bulk and first cost of apparatus are great factors. Energy for starting can be stored in the form of water in a tank or boiler having large volume. In storing high-pressure air it is not practical to store the energy in such bulk. It is rather necessary to store the air in individual bottles of relatively small capacity and great weight. For this reason it becomes very evident that more energy can be stored in the boiler than in the bottles for the same weight and space occupied.

As to cost, the air for starting is used for starting alone and so there is a direct expense chargeable to starting alone. On the other hand, the water container can be used as an auxiliary boiler for steam-operated auxiliaries. Hence this element cannot be properly charged to the cost of starting the engine.

As to reliability, there is no argument. Steam has proven its reliability, and the only advantage of the oil engine is its economy. The disadvantage of the oil engine is its lack of reliability and a certain feeling of doubt which exists with all new elements. The matter of unreliability can be done away with by the use of steam as outlined. There is a limit to the slowness with which the oil engine can run. Suppose it necessary to run below this limit, can air be depended upon? Apparently not. When the engine is running slow no great amount of power is generated, and this condition will not be needed for any length of time. The chief need of this extreme slow speed would seem to be in picking up a tow at sea or in making dock. In maneuvering to make dock there have been several instances where the air has

given out and the navigator has had to stand by and watch his vessel strike in a way which must be particularly annoying to a good navigator. This feeling of uncertainty as to the condition of the air supply must do much to make the oil engine unpopular with the bridge force. On the other hand the use of steam drawn from the auxiliary boiler would do away with all this, and the navigator need not know but that his engine is a steam engine. He can come within maneuvering distance of the dock and then go on to the maneuvering cycle and bring his vessel up to the pier with absolute assurance. In order to make this possible in the oil engine it is necessary only to provide the engine with means for jacketing the cylinders with live steam. In fact, for the last case considered—that is, of maneuvering to come to a dock—it will be necessary only to cut out the cooling water and to depend upon the heat of the cylinder walls to prevent undue condensation. This is not a condition which need offer much difficulty, as the engine will simply follow the practice of the present steam engine.

The whole idea of this design is to reconcile the peculiarities of the oil engine to that thermodynamic practice which has been found to be best in the use of the steam engine. The cylinder walls of the engine are jacketed, not to make them cold, but rather to prevent them from becoming too hot. It seems to be a necessary line of development to study this matter of temperature of the engine and to see that the engine be not reduced in temperature below that point which is desirable, just as in the steam engine the point of the best practical vacuum becomes a matter of judgment and not a case of obtaining the greatest possible vacuum regardless of cost.

THE ACTUAL DESIGN SUBMITTED.

In presenting this design no attempt is made to claim perfection. The aim has been to present a design which will be a basis for improvement. It is felt, however, that to submit general ideas without presenting working plans is apt to leave the reader in doubt as to how the general scheme will work out. If this design starts thought and discussion it will not fail of its purpose. It is felt by the author that the design submitted is superior to any of which he is aware. At the same time it is fully recognized, that with so much detail as is found in such a design, many of the minor details can be wisely criticized. It is felt that such can be improved upon or altered without altering the type of the engine.

The general ideas have been presented first, in order to make clear the aim of this type of engine. This design is a four-cycle type, but many of the principles involved can be applied to a two-cycle type, although the four-cycle is favored by the author. If the elements taken up are found to be sound, the practical application of these elements to a design of different size and use will be a matter of application of recognized principles rather than a matter of design along new lines. It has been hoped that it would be possible to make it perfectly clear that an oil engine can be designed in the same manner as a steam engine, and that it is not necessary to buy experience from foreign manufacturers. It has been hoped that this paper

would bring out the fact that the oil-engine field is still an open field in which much remains to be done, and that these results can be as well obtained by an organization which starts out to design its engine according to needs, in place of buying and remodeling an unsuitable design. It is felt that, if the oil engine is to be built, one of two courses must be followed. The first is to buy from some manufacturer a design which absolutely suits, and to build without modification. The second is to thoroughly understand the principles of the oil engine and then to design the engine to suit. It is felt that no perfect engine exists today and so it is far safer for the manufacturer to realize this condition and absolutely depend upon his own design. The point is, if the original design is to be altered at all, who shall say what shall be taken and what shall be rejected? Does it not seem wiser to pass upon every element by itself, judged by the best which is known? It has been the aim, so far as possible, to collect and present these known elements which are peculiar to the oil engine.

THE DESIGN.

This design was to fill the following conditions:—

Brake horse-power in one engine	450
Revolutions	450
Length overall not to exceed	14′ 9″
Width not to exceed	3′ 8″
Height above center of shaft not to exceed	6′ 0″
Distance below center of shaft not to exceed	23″
Weight not to exceed	26,000 lbs.

It is thought that all the conditions can be met or exceeded in this design. To meet the conditions a 6-cylinder design was fixed upon, with cylinders of 13-inch bore and 12-inch stroke. This gives a piston speed of 900 feet at the desired speed, and it is thought from data in hand that the power can be slightly exceeded.

The weights which have been figured out from the details are about as follows:—

Bed plate	3,840
Crank case	2,830
Cylinders	2,200
Heads	1,500
Pistons	960
Wrist pins	195
Connecting rods	1,166
Main bearings	1,310
Shaft	970
Cam shaft bearings	528
Total	18,219

The air compressor is not included, nor the piping. The weight has been figured out to show that the engine comes somewhere near to the limiting figure. On the other hand, the brake horse-power was set for 450. Allowing 90 for the correct effective pressure on the pistons to give the brake horse-power, the calculations for brake horse-power will be as follows:—

$$\frac{132.7 \times 90 \times 900 \times 6}{33{,}000 \times 4} = 496 \text{ B. H. P.}$$

132.7	is piston area in square inches.
90	is the M. E. P. factor.
900	is the piston speed.
6	is the number of pistons.
33,000	is the foot-pounds per horse-power per minute.
4	is the divisor to account for the four-cycle type.

It is expected that this design will be severely criticized. If there were nothing about this design to criticize the writer would not be inclined to put in the time necessary to prepare this paper. It is, however, felt that this design can be defended upon all lines of attack. The first serious criticism will perhaps be on this factor of 90 in the power calculation. The normal practice is a mean effective pressure of about 100 and a mechanical efficiency of 75. This will give a factor of 75. This factor of 90 is used because the mean effective pressure will be increased on account of a lowered pressure of compression, and the mechanical efficiency will be raised for the same reason. It is felt that a mean effective pressure of over 120 and a mechanical efficiency of over 80 would be perfectly reasonable. This increase in mean effective pressure and in the mechanical efficiency will be explained somewhat by Plates 16 and 17, which were prepared after the paper on "The Thermodynamics of the Marine Oil Engine" had been submitted, in an attempt to meet criticism on that paper. These were not presented in argument on that paper because the criticism was not forthcoming.

The first question to be settled in the design of an oil engine should be what pressure of compression shall be selected for the full-compression pressure. The writer is intolerant of restraint. The oil engines in use today have jacketed heads and use a pressure of compression of 500 pounds. This is used because Dr. Diesel used it. Dr. Diesel took the suggestion of du Rochas and made it practical by fixing the pressure of compression. How he arrived at this is unknown, Too great credit cannot be given to Dr. Diesel for his progressive spirit. Too great condemnation cannot be given to his imitators who, with additional data on hand, still copy the cycle which Diesel hit upon as a result of his groping around in the dark. In this submarine engine the compression at full load was fixed at 200 pounds. The clearance was found to be 15.6 per cent and the height of the clearance to be 2¼ inches. This design was worked out, not alone to illustrate to the Navy Department certain ideas in oil-engine construction, but also along lines upon which the author

was willing to stake his reputation. In order to start this engine steam would have to be supplied to the water jackets. This is undesirable for such a small engine, but the submarine of today is not the submarine of tomorrow. When the offer was made to design a submarine engine reference was made to such an engine as would be needed in the large ocean-going submarines in which a speed of 25 knots would be obtained. These submarines have been designed and the speed reduced to 19 knots because of the inability to obtain the above speed. To produce steam needed to warm this engine will not present any great difficulty, and the engine will be greatly improved by an increase in power and an increase in mechnical efficiency. As soon as the engine is firing, water will be needed in the jackets and the engine will then follow the conventional Diesel in its cycle.

Extreme emphasis has been laid on the fact that this design is not claimed to be mechanically perfect. If put into the hands of a first-class draughting force and the several details gone over with great care, the result would be a great improvement. But the contention is made that the designer should keep his hands off the general arrangement.

The general arrangement will be a good place from which to begin a consideration of the engine as a whole. No air compressor is shown because it is felt to be very bad practice to couple the air compressor to the main shaft as is too often done.

Let us assume that the air compressor be coupled to the main shaft of the engine. In such an arrangement a fixed amount of air is handled by the compressor for each revolution. This arrangement is used when air is used for starting the engine. The result is that the amount of air which should be compressed is a varying quantity. After the starting cycle is completed the air consumed for starting must be replaced. To meet this condition the capacity of the compressor must be in excess of that needed for normal operation. If the engine is run a long time without a starting cycle, then obviously an undue amount of work will be done in the compressor. If the air compressor be a separate auxilary plant, then this variation in air supply can be handled without any excess of high-pressure air being accumulated. Again, let us assume that the valves of the compressor are not working properly and that the vessel is on a run. If the compressor is direct coupled, all that can be done is to stop the engine and correcct the trouble. It may be very essential that this be not done. If the air compressor be a separate plant, then it will be possible to speed up the compressor to make up for the leakage, and the vessel can be kept under way. The loss in the air compressor will be appreciable, but this loss will be far less than that caused by stopping the vessel. This explains the reason for not having the air compressor direct coupled to the main shaft.

The engine is divided into two sections of three cylinders each with the couplings, reverse gear and fuel pump placed between the two sets of cylinders. It is felt that by this arrangement the stresses in the cam shafts will be reduced below that of the arrangement where the cam shafts are driven from one end. There is space available due to this arrangement for placing the fuel pump between the two

sets of cylinders. It has been stated that the fuel and the admission valves must be subject to regulation as to timing, etc. The starting and exhaust valves do not need this regulation. For this reason the fuel and exhaust valves are placed on the front side of the engine and the starting and admission valves on the back side. It is practical to vary but one set of valves from one cam shaft, therefore the proposed arrangement. The cam shaft as designed is composed of a shaft and a sleeve. The drive is on the sleeve and the fixed valve is driven from the sleeve. The shaft which is within the sleeve can be varied in its position relative to the sleeve. The cams for the variable acting valves are operated from the shaft within the sleeve. This means that at one side the fuel valve is operated from the shaft and the exhaust valve from the sleeve, while on the other side the starting valve is operated from the sleeve and the admission valve from the shaft. This is shown in the plan of the cam gear. No defense will be offered for this mechanical arrangement. It was worked out after years of scheming and perhaps a better arrangement can be produced to get the same result. This result must be obtained, however. The drive from the sleeve to the shaft is composed of a spiral key and keyway similar to that used in the side-shaft steam engine for reversing. The timing of these valves is regulated by the levers shown at the end of the cam boxes. It is claimed that this device is a working and practical arrangement. Nothing more is claimed for it.

REVERSING.

The motor ships run by four-cycle engines are for the most part reversed by swinging the cams clear of the cam shafts while the cams are being moved along the cam shafts. This is needed for a multi-cylinder engine, because otherwise one or another set of cams would always be prevented from moving by coming in contact with its roller. This difficulty is remedied in the motor ship, as has been stated, by swinging all rollers clear of the cams during a change of cycle. For a compact engine this arrangement is rather clumsy. The same result obtained by this swinging movement must be obtained. In this engine it is obtained by a modification of the roller and roller fork. The rollers are carried on a long pin with considerable play on each side of the rollers. The rollers are held in a central position by means of balanced springs. With this design, in changing from one cycle to another, those cams which interfere with a roller will simply push the interfering roller to one side and the other cams are not prevented from attaining their new position. The displaced rollers take their normal position as soon as the cams have rotated enough to allow this action. In making the change from one cycle to another in a 6-cylinder engine there will be normally 24 cams bearing on the cam surfaces. These cam rollers must be held down by strong springs in order to assure prompt action of the valves at high speeds. To move the cams along the cam shaft would naturally call for the expenditure of considerable effort. In order to make this action easier and the maneuvering of the engine more prompt a provision is made on the cam boxes whereby all cam rollers may be simultaneously lifted about 1/32 inch. This will be

enough to take the pressure off the cams and yet not enough to interfere with the valve action.

The start of this engine is obtained by this same lever. The tappet rod which operates the starting valve is lifted by a further motion of this same lever which will open all the starting valves. This sets the engine in operation, and the valve timing determines the proper direction of rotation. This is done by having a longer and different shaped cam acting on the starting valve tappet. This will be wasteful of starting energy, but the waste will not be excessive and the desired effect will be an instantaneous response to the reverse lever.

The desired operation of the admission valve is obtained by means of varying the timing of the admission valve cam and by making the valve automatic as far as opening is concerned, and mechanically operated as far as closing is concerned. This is done by having the valve cam simply release the admission valve. When this is done the valve stays open as long as the suction stroke is in progress. A partial suction stroke may be obtained by advancing the admission valve cam. In this way the valve opens, but not until the suction stroke of the piston begins. On the other hand, when the valve cam completes its operation the tappet rod falls and closes the admission valve. The author is of the opinion that no novelty exists in this method of operation.

FUEL AND FUEL FEED.

This is a most important matter and this design is unquestionably superior to the submarine engines at present installed in the United States submarines. If we divide the method of fuel feeding into two classes we shall have the present class and the proposed class. We may call these two classes the Diesel type and the Wentworth type. As far as the author knows he is the first to propose this modification. Plate 19 shows this difference. In the Diesel engine the operation of the fuel pump is slow. The plunger is practically moving all the time, but the stroke is so short that the speed of the plunger is very slow. The author has found by actual experience that a fast-moving plunger will give better results than this slow-moving plunger. The result is the fuel pump, as shown in detail. The feature of this pump is a floating piston. This piston or plunger is lifted in the delivery stroke by a lever operated by a cam. The plunger is returned by the springs at the bottom of the plunger. The plunger is at all times kept against the lever by means of the spring. The motion of the lever determines the stroke of the plunger, and the movement of the lever is controlled by an eccentric shaft. With full eccentricity of the shaft up, the lever is held so that the cams clear and no fuel is delivered. With the shaft turned an angle of 180 degrees the maximum stroke of the plunger is obtained. Any desired position may be obtained for the shaft between these two extreme positions and so the amount of fuel delivered may thus be governed. The feature of this pump is not only to deliver exactly the fuel required, but to deliver this particular amount and at just the moment it is needed. By varying the position of this set of cams the action of the fuel pump may have a different timing.

In place of a long suction and delivery stroke the two strokes are very sharp and quick, the plungers being idle the rest of the time.

Now referring to the plan of the fuel valve it will be seen that this valve really is a double valve. The air for injection has one seat and the fuel comes through another seat. The lift of the fuel plunger should be timed to act with the opening of these two valves so that the fuel will be delivered by the pump directly into a stream of moving injection air. In this way the system can take care of any grade whatever of fuel. It has been pointed out that the trouble with most fuel valves is that the fuel is delivered to the fuel valve and allowed to come to rest, and then the air has to get in and around the fuel so as to deliver it in small portions and not as a whole. This design of fuel valve absolutely does away with any difficulty along this line.

Objection may be made to the care needed in timing the two elements—the fuel pump and the fuel valve. No reply is needed to such an argument. It is no more difficult than to time the spark on a gas engine. Another feature of the fuel valve is that the fuel starts after the air has started, and stops while the air valve is still open. The result is that the fuel valve should give no trouble with clogging—it is cleaned by air after each delivery stroke.

Attention is called to the fuel heating tank. Here the fuel is heated by means of a coil of steam pipes within a tank. By this means a heavy, sluggishly moving fuel may be made to flow as freely as the present gas oil. The result is a saving of 50 per cent in cost. With the particular type of fuel valve shown, no trouble should be experienced in getting this fuel too hot, beyond gasifying it, which would give an unequal action of the engine if carried to excess.

All engines at present used in the United States submarines are said to use this comparatively high-priced gas oil. The engines shown in this design will run from the start on any grade of fuel, and it is thought that no other design of marine oil engine will do this. The author is pleased to state that an engine has actually been operated in this manner on low-grade California oil.

STARTING.

In the paper on "The Thermodynamics of the Marine Oil Engine" a great deal was said about the use of steam for starting the oil engine. There is no question about the advantage of steam in connection with the oil engine. At least the author has studied the matter from all viewpoints and can find no fault with the use of steam. Under these circumstances it is no more than right that some consideration be given to the type of steam generator which would give satisfaction in this service.

The steam generator must have a large water body. There is one disadvantage to this—that it will take a considerable time to get this water body up to the desired temperature. This is true, but we are not handling a toy or quick-acting device. This type of engine is designed for actual service conditions seven days in the week. By this is meant that the engine is designed to be kept ready for use

seven days in the week, even if used but once a month. While it would take a long time to get this water body up to temperature it would take but little energy to keep it there. For the navy this means that the watch on duty should see that this steam pressure be kept up. The fuel expenditure will be small.

The probable change in the submarine will be to enlarge it to fit it for duty as a commerce destroyer on the high seas. For men to work at their best they must be kept reasonably comfortable. This does not mean to live in cold, damp quarters. The vessel must be kept heated and the auxiliaries run from the waste heat energy of the present-day engine. It is strange that this has not been taken up before, but because it has not been is no reason for further delay.

The steam generator consists of a furnace with an air-tight door. When the ship is going into commission, or the boiler is being cut in, this door will be open and the steam pressure is generated by the combustion of fuel in this furnace. After the engine has been started, the exhaust from the engine should enter the outer casing of the boiler at the top and go around this casing till it enters the furnace, where the gases would follow the natural course of gases in a boiler and leave to go up the stack. Like other features in this design, no doubt better designed boilers can be worked up. The design of boiler is given to show one practical arrangement. The aim is to get a large water body so that a very great amount of energy can be given off for a very short time. This means that if we use this boiler under the combustion of fuel alone it might be able to generate, say 25 horse-power. For the time needed on the starting cycle it is easily possible to generate from 500 to 2,500 horse-power according to the design.

There are two types of engines to be considered in taking up the oil engine broadly. They are the commercial engine and the naval engine. Either of these two types may be highly successful in the field for which it is designed and yet leave much to be asked for in the other field. The naval engine should have a great reserve of power, while the commercial engine should have endurance so that it may run at full power all the time and still have a small upkeep charge. The general qualifications for the two types would seem to be somewhat as follows:—

Naval Engine.—In the naval engine it is desirable to have a higher pressure of compression at full loads and a greater variation in pressures of compression. In this type the partial compression cycle would give higher efficiency at partial loads. At the same time this engine should not be designed for the present full-load pressure of compression.

Commercial Engine.—This type would vary from the naval type in that the pressure of compression would be a minimum. The engine should be designed with as perfect a scavenging arrangement as possible and the normal operation of the engine would be full power.

It may be seen that an engine designed under these conditions for one service would not be the ideal engine for the other service. The object of this paper is to give data so that an engine may be designed from these theories to fit the particular needs of the vessel in which it is to be installed. In 1904, when the author began this work, it was not intended to work along a stock design which would fit

all cases. This is the method which should be followed if the oil engine be a mechanical device which is not capable of being developed along scientific lines. It is hoped that this paper and the preceding paper have made it clear that the oil engine has a theory behind it which is even more complex than the theory behind the steam engine, and that to get the best there is in the oil engine particular attention must be paid to the service for which the engine is designed.

If this paper has not failed, it should be possible for the designer to take the data and suggestions contained in this and in the preceding paper and develop a design to fit the needs. Experience and experiments are needed for this work. Experience can be obtained by making a start. Experiments should be as few and as far between as possible, and should be along logical lines and not be made blindly with the hopes of stumbling upon something. Experiments are being carried on in Europe. Why is no development work being done in this country? The only answer can be that this condition results from a lack of a broad conception of the principle of the engine. We have the greatest wealth of natural fuel for this engine. Does it seem wise to wait for several years for an engine to be built for us? This would be the wise course if there were any reason why we could not develop our own engine. Europe is but just beginning to understand this engine. Why not study the engine from a thermodynamic standpoint and see what the conditions are which must be overcome in this work? Two-thirds of the fuel energy can be saved by using the fuel oil in this type of engine in place of using it under a boiler. Is this not an incentive for a better understanding of this type of engine? The ideas which have been suggested may be false. They are, however, better than no ideas and should serve, in the absence of other and better ones, as a starting point. It is confidently thought that the ideas which have been presented will be found to be entirely practical and to offer great advantages over the European practice. This, however, can only be settled after the final development of the oil engine. If these ideas have defects, the proper place for these defects to be discovered is in such a body as this. If they can be successfully defended here, they become, at least, worthy of consideration by the engineering fraternity at large.

The author desires to make acknowledgment of the aid rendered him, while preparing this paper, by his friend, Dr. Geo. H. Ryder.

DISCUSSION.

The President:—Gentlemen, you have heard the paper entitled, "The Design of an Oil Engine," and it is now before you for discussion. Is there any discussion?

There being no discussion, I will extend the thanks of the Society to Mr. Wentworth, and we will proceed to the next paper, No. 4, which is entitled, "Aeronautics in Relation to Naval Architecture," by Naval Constructor H. C. Richardson, U. S. Navy, Member. In the absence of the author the paper will be presented by Naval Constructor Linnard.

Naval Constructor Linnard presented the paper.

AERONAUTICS IN RELATION TO NAVAL ARCHITECTURE.

By Naval Constructor H. C. Richardson, U. S. N., Member.

[Read at the twenty-fourth general meeting of the Society of Naval Architects and Marine Engineers, held in New York, November 16 and 17, 1916.]

The most intimate point of contact between aeronautics and naval architecture exists in the design of floats for aeroplanes, and I shall confine this paper to that subject although the question of stream line forms and the pressure and flow of air on such forms and on flat and cambered surfaces is also closely related to naval architecture.

Early in 1911 work was started at the model basin at the Washington Navy Yard, with a view to the development of floats for aeroplanes. This work has been constantly followed up by making tests of model floats of all descriptions, and particularly with models of floats actually furnished, or proposed, for use with naval aeroplanes. In addition to this, series of models embodying variations of particular features were tried from time to time, covering a wide range of possible useful features, and, where such models showed sufficient merit, full-size construction has been carried on, and the full-size floats have been given tests in actual service. A detailed account of the complete series of tests would be too voluminous for reproduction, and would cover many defective types, so that I shall enter only into a general discussion of types and the requirements for floats for naval aeroplanes.

It appears well to point out at once the differences existing between the conditions of use of aeroplane floats, and those met in the use of ordinary displacement vessels, or vessels of the hydroplane type. The principal differences arise from the fact that, as the square of the speed increases, the lifting power of the wings becomes more and more important, and the load carried by the aeroplane float constantly diminishes until at the get-away speed no load is any longer carried by the float. At the higher speeds near the get-away conditions, the form of the bottom of the float becomes unusually important, due to a prominent suction effect which is present if any downwardly bowed lines of flow are presented.

It might readily be imagined at first thought that what proves the best type for hydroplane hulls would naturally be the best type for aeroplane floats, but the reason just mentioned may operate seriously against certain types of hydroplanes for aeroplane use, for the hydroplanes themselves constantly carry the same load, whereas aeroplane floats carry a diminishing load, are consequently less deeply immersed, and, therefore, present in general a different set of lines to the flow of the water than is the case with hydroplanes. Besides this, a hydroplane is never projected suddenly at high velocity into the water with any lateral velocity. This, however, is frequently the case with aeroplane floats, which must be able to make skidding landings, or get-aways, across the wind without danger.

The most prominent effect of the special conditions of operation of aeroplane floats is that of the greatly reduced resistance at high speeds. Plate 31 indicates decided differences existing under ordinary displacement conditions and the conditions governing the use of aeroplane floats. On this plate curve *A* represents the resistance of a simple hull of constant displacement. Curve *B* represents the resistance of the same hull run at displacements corresponding to speeds. Curve *C* is the same hull as that for curve *B,* but is fitted with submerged blades; while curve *D* shows a typical resistance of a twin step float run at displacements corresponding to speed. The great advantage, so far as resistance is concerned, due to the lift of the wings, is clearly apparent from an inspection of these curves, and the addition of submerged blades clearly increases this advantage so far as resistance is concerned. But the performance of such blades is decidedly tricky, and although they have been used in a few instances they are considered tricky and unsatisfactory and unsuited to use in rough water.

A matter of considerable interest is that two different states of flow may be encountered at the same speed, depending on the manner in which the speed is approached. Thus, an aeroplane getting under way will require full power to attain the planing condition at about 25 miles per hour. However, once planing speed has been attained, it is possible to ease off the power very decidedly and still maintain planing at a lower speed.

When using water blades to assist in planing, a critical condition appears, and, if the blades are heavily loaded, this causes a sudden failure of lift as the blades approach the surface. When this happens the flow suddenly breaks from the back of the blade, causing a sheet of spray to rise at about 60 degrees to the surface of the water, and this appears to be independent of the sharpness of the edge of the blade itself. Following this failure in lift, the float then settles quickly until the original flow is re-established, when the blade again lifts as before and proceeds to follow the cycle of performance just described.

The suction effect referred to was discovered in an attempt to reduce frictional resistance of the float to a minimum by the use of a parallel middle body having semicircular midship sections with ogival ends. This form behaved admirably at moderate speeds, but, when the get-away condition was approached, the model, instead of planing, indicated a strong suction effect and proceeded to lift sheets of spray well clear of the surface. Finally, at the get-away condition, with the model counterweighted to a zero displacement and just in contact with the surface, the suction influence of the curved bow and buttock lines was sufficient to drag the float down into the water until the deck was flush with the original surface, and a complete glassy sheet of spray was lifted several feet clear of the surface of the basin. The resistance was abnormally high. This effect in modified form has been found in several types of floats and in several instances has produced failure of designs, or seriously affected their performance. The effect may be readily understood by suspending a spoon, holding the end of the handle lightly between the fingers, and then letting the bottom of the bowl of the spoon touch a stream from a hydrant.

Having considered the special conditions which affect aeroplane floats, as distinguished from those affecting displacement forms, let us now consider what is required of aeroplane floats.

When adrift the floats must provide buoyancy and have sufficient reserve of buoyancy to provide against loss due to a damaged compartment.

Sufficient water-line inertia and freeboard are required to provide initial and reserve stability in a strong wind in the open sea. This problem is unusually difficult, because of the unusually high position of the center of gravity and of the requirement of keeping the wings and propellers well clear of the surface, and of keeping the center of gravity close to the center of lift. Those inclinations produce a rapid movement of the center of gravity, which must be exceeded sufficiently by the resultant change in the center of buoyancy. Sufficient initial stability must exist to provide against the force of the wind on the extended wings, which may be rolled to strong lifting angles.

When drifting it is desirable that the aeroplane should head into the wind. This is difficult to attain by control of form and may require the use of a sea anchor.

Under way at moderate speeds the aeroplane must steer readily in all directions and be able to maneuver in close quarters so as to get alongside the ship.

Water rudders are not always successful on such short floats as are usual, and are objectionable from handling and stowage points of view. If the water rudder is a part of the air rudder, action becomes confused in a cross wind, and sharp handling is necessary when the water rudder breaks clear of the surface.

Under way at high speed, particularly near the get-away speed or landing speed, the bow must have sufficient bearing power to prevent nosing under in a rough sea or a badly judged landing. The form must also be such as to avoid undue pounding and the throwing of spray into the propellers.

In order to avoid the requirement of excessive power to drive the floats, planing should begin at moderate speeds—in the neighborhood of 25 miles an hour in a calm. Planing is readily attained by the use of large areas of planing bottom, but too rapid planing is not desirable, and a compromise is required because of the different water speeds involved when getting away in a calm or when heading up or down wind. If too much planing is present, the aeroplane may be tossed off rough water at less than flying speed, or before the air controls become effective. This always results in severe pounding and may cause the aeroplane to return to the surface in a dangerous attitude. If after planing is attained the attitude of the float relative to the surface can be modified, the wing lift can also be modified, and the actual get-away becomes controllable within limits. This latter feature is very desirable.

When getting away or landing it is extremely desirable that the forces acting on the floats should be moderate and act with small moment arms about the center of gravity, so as to introduce moderate disturbing forces and require a minimum use of the air controls and maintain the proper attitude of the aeroplane.

In the air the floats should present a minimum resistance and interfere as little as possible with the flow of air to the supporting surfaces and the air controls.

They also should not introduce disturbing influences on the center of pressure of the aeroplane, as this is also involved in the equilibrium of the aeroplane in flight.

All of the preceding qualities must be attained to as high a degree as practicable in floats, which at the same time must be rugged enough to stand severe punishment on the surface and still be of the lightest possible construction. The solution is necessarily a compromise. Buoyancy and stability require forms and dimensions which conflict with the best aerodynamic forms and the requirements of moderate resistance and weight. Planing in flight also requires a form of bottom which does not readily meet stream line requirements.

At the model basin at the Washington Navy Yard a speed of over 15 knots is available; this admits of the use of one-ninth size models for a get-away speed of 45 miles per hour, and this size model is generally used.

The first condition to be provided is that of loading the model to the displacement corresponding to the speed. The assumption is made that the lift of the wings increases with the square of the speed. This is only approximately correct, but serves well for the purposes of comparison. It is not exact, for the attitude of the aeroplane is dependent on the amount of air control existing, and whether it is sufficient to overcome or modify the effect of the forces acting on the floats and thus obtain control of the angle at which the air surfaces act. As these effects cannot be anticipated, or the control be determined or applied, this assumption does not appear unreasonable, and the comparison of model and full-size performance appears to justify this and the other assumptions made.

The model is usually set at a trim of 3 degrees by the stern from the normal water line, as numerous experiments indicated this to be the average condition. A direct comparison was made of a one-quarter size float under the artificial conditions assumed and the same float fitted to a model aeroplane to the same scale. Except at low speeds where the tip floats, which are not used in model tests, introduced increased resistance, and at high speeds where the complete model was not under flying control, the agreement was very satisfactory, and at the point of maximum resistance, which is of the greatest interest, was practically in exact agreement.

The models are first towed from a parallel motion system, which allows the model to rise or fall under the influence of the planing or suction effect while maintaining a constant trim relative to the surface. The rise or fall from the initial condition is recorded and indicates the planing power of the model. The gear is so arranged that the model is readily counterweighted to the desired degree for each condition.

Plate 32 is a complete record of test of model No. 1844. This test is that of a model of a twin-float design of a 2,000 pound aeroplane. The model was one-ninth size and the corresponding speeds, therefore, were one-third those for the full size. Get-away was assumed at 45 miles per hour.

Curve *B* shows the gross resistance of the model and towing gear, and curve *C* the net resistance of the model.

Curve *D* shows the change in trim at each condition due to the planing power.

Curve *F* shows the modification of the resistance curve when the model is

towed free to trim, the model pivoting about a point corresponding to the relative position of the propeller thrust.

Curve *G* shows the water-planing power for this condition.

The performance indicated is typical. At first the water resistance rises rapidly, then as the influence of the wing lift becomes appreciable and the model begins to plane, the resistance reaches a maximum at about 6 knots for the fixed condition, and 6 knots for the free to trim condition. The resistance then falls away steadily for both conditions, but, in the case of the free to trim condition, holds up longer and usually has a secondary hump. As at high speeds the aeroplane is usually controllable, the fixed trim condition is attainable and, therefore, representative. At low speeds, however, the squatting effect may predominate, or may be even purposely produced to advantage, as the maximum resistance for the free to trim condition is practically always less than that for the fixed trim condition.

From a comparison of similar models of 2,000-pound and 6,000-pound floats, Froude's law of comparison appears to apply satisfactorily, and it also appears that dimensions proportioned to the displacement have planing power in proportion to the displacement, assuming the same get-away speeds in both cases and that the loads correspond to speeds.

Many forms and dispositions of floats have been proposed and tried, and for inland waters several successful forms now exist, but for work in the open sea no form is yet known to have all the required qualities.

The first success was attained by Curtiss with floats of an exaggerated blade form, but these were not as satisfactory as the normal rectangular section float having a skidform profile. This is a simple and successful form for inland work, and it seems to matter little from a resistance point of view what form of bow curve is used. An examination of the curves of Plate 33 will show the close agreement in performance of bows having widely different forms of curvature. Various other forms of bows were tried—convex, concave, flat sloping bows, corrugated bows—and all show essentially the same characteristics.

The influence of steps has been tried—one, two, and up to six. From a resistance point of view it appears unnecessary to provide more than two steps for aeroplane conditions. The first break is usually placed nearly under the center of gravity, and the second forms the stern of the float. If both steps are inclined in the same sense a biplane float is formed, but if the after step rises relative to the forward one, it more nearly approaches the monoplane or single-step form, which has desirable qualities. This is the form which has proved so successful in the flying boat and is the form used in model No. 1844, whose resistance curves have already been referred to. Ventilation of the steps facilitates quick planing and is useful, but is not essential if there is ample reserve of power.

Interference between twin floats at the separation usual in practice appears inappreciable, except at very low speeds.

Flat-bottom floats pound heavily and the flat-bottom-step type porpoises strongly, unless it is handled very nicely, even in smooth water.

The introduction of a moderate V-bottom greatly reduces the shock of landing

on smooth or rough water. All straight V's throw a strong sheet of spray at the bow. This sheet of spray appears to be independent of the true bow wave. It can be suppressed by the use of hollow V-lines at the bow, but this form is difficult to build strongly and has bad steering tendencies when trimmed by the bow or when making a skidding landing or get-away. A simpler method of suppressing this bow spray is the use of mud guards, so-called for obvious reasons.

The V-bottom also greatly reduces the danger of sticking a wing under on a skidding landing, or when running at high speed across the wind.

The use of fine lines at the bow or stern is not very general, because of the need of longitudinal stiffness. Such lines steer badly, and there is some evidence of the suction effect being present. It is not improbable, however, that a compromise between such lines and the V-bow may work out in solving the seagoing problem.

In construction details in this country the boat-builders' influence is just being asserted. The principal builders have followed a box-like construction not disposing of their material to advantage.

In recent efforts to develop a stream-line form of float, embodying as much as practicable the requirements enumerated, the following features have been developed:—

Plate 34 shows views of these floats in different stages of construction. The general form is as nearly stream line as practicable, having a curved deck comprised of two-ply spruce, applied diagonally, one across the other, with cotton sheeting and marine glue between the plies. This construction eliminates the usual deck joints and provides the arched form with diagonal bracing, continuous from chime to chime.

Through the center of the float a longitudinal truss provides the backbone of the construction. Two-ply bulkheads support the float attachments, and the principal bulkheads are tied to each other and to the step by a two-ply fore-and-aft bulkhead built into the center-line girder. These bulkheads are bound by oak ribs and intermediate ribs of oak support the top shell.

The bilge stringers and the keelson are continuous, the step being formed by tapered liners. The step is of oak, as when grounding, or when planing at high speed, the loads are concentrated at the step. The bottom is two-ply spruce, the inner ply running athwartships and the outer ply running diagonally outboard and aft from the keel to the bilge stringers.

Cotton sheeting and marine glue are used in all two-ply work and the plys are held together by special clinch nails of brass.

The bottom is supported by the keel and bilge stringers and an intermediate longitudinal, which are in turn supported by the step and bulkheads. The stem and stern pieces are of spruce, shaped to take the longitudinal members and rabbeted to receive the shell planking. The system of bottom planking and longitudinals eliminates the use of bottom frames and really provides continuous framing in the planking itself, similar to Hands' original V-bottom construction. This type of bottom planking appears resilient and strong.

In assembly all butts are covered with glue. All woodwork is given two coats of shellac as soon as it is in place, and is finally given two coats of varnish to prevent the absorption of moisture.

All boundaries of the bottom are sheathed with brass strips set in marine glue. This affords protection and insures water tightness. The float attachments are locally reinforced and strengthened to transmit the loads to the important members.

The method of construction involves the use of a wooden form shaped to the molded lines and cut into sections to allow of removal.

The center-line girder is next assembled with the bow and stern blocks and the step. This is then assembled with the form in which the slots for the ribs and the bilge stringers have already been cut. The frames and stringers are then bent and set and faired flush with the surface of the form. Next the inner ply of planking, which has already been shellacked and varnished on the inner face, is applied and secured to the frames and longitudinals by means of screws. Steaming is unnecessary. In some cases it is necessary to humor the sharp curvature at the ends by the use of hot water applied with a swab.

This first ply of planking is then coated with marine glue and the sheeting is applied, followed by the second ply of planking, which is treated with marine glue as fast as each piece is shaped. The second ply is secured in a manner similar to the first ply. The seams of the first ply are traced on to the second ply in pencil, for the purpose of laying out the nails securing the two plys together. Once the second ply is laid, these nails are driven at intervals of about 2 inches along the margins of both plys of planking, the ends of the nails projecting into the wooden form. The form is now removed, the nails are clinched, and additional quilting nails are systematically driven and clinched. In the meantime the bulkheads and bottom planking have been assembled roughly to dimensions on a flat slab. The bulkheads are now neatly fitted and inserted and secured to the frames by screws and glue. Next, the intermediate longitudinals are placed and secured and all special bracing and fittings for the float attachments are placed and the bottom frames of the bulkheads secured. The bottom planking is now carefully fitted and the drain plugs installed in the proper locations. The hand holes and the holes for the ventilating tubes are laid off, cut, and reinforced, and then the bottom planking is applied and secured. The ventilating tubes are next secured. The entire float is now turned over to the painters, who carefully sandpaper the surfaces and apply two coats of shellac and two coats of varnish. After this is done the step casting, edge strips, false keels, mud guards, and deck fittings are applied.

Each of these floats, designed for 1,000 pounds displacement and 60 per cent reserve buoyancy, weighs, complete, 125 pounds. The principal dimensions are:—Length, 15 feet; maximum beam, 24 inches; maximum draught, 14 inches.

The floats illustrated have been used in service with very satisfactory results. The aerodynamic properties of these floats are good. They have the least resistance when the deck is inclined at —3 degrees to the wind, and in this position have no lift; consequently, they present a minimum disturbance in the equilibrium of the aeroplane.

It may seem queer that metal floats have not come into general use. There are several reasons for this, however, the principal reason probably being that the form of floats is as yet nowhere near standardized, so that metal construction for special cases would prove excessively costly. But another reason is that when the attempt is made to build floats of the dimensions required on weights which compare favorably with wooden construction, it is found that the metal itself is so thin that it lacks the required stiffness to preserve its form under service conditions; further, that this thickness provides too little margin for the effects of corrosion, particularly in salt water; and, in particular, the bottom itself would require an elaborate system of support in order to prevent it bending badly under the heavy pressures encountered in service. However, as the number of aeroplanes in service becomes greater and the form of floats becomes to a certain extent standardized and larger, it is probable that metal construction can be satisfactorily solved.

DISCUSSION.

The President:—Gentlemen, you have heard the paper which has just been presented, entitled, "Aeronautics in Relation to Naval Architecture." Does any gentleman wish to discuss this paper?

Mr. Elmer A. Sperry, *Member*:—This paper is certainly a contribution to our records of great value, and I think the Society is very fortunate in having it. The question treated by Mr. Richardson is of much practical importance. By the way, Mr. Richardson has gone into it more deeply, probably, than any one else on this side of the Atlantic, and possibly in the world. He has been given excellent facilities in the use of the experimental tank at Washington, and the problem itself is fraught with a great deal more difficulty than is at all apparent on the surface.

When the America was finished and ready to be tried out at Hammondsport two years ago, as you will remember, the very greatest difficulty was experienced in getting the machine to break away from the water. The machine would fly all right, fly with only one of its engines very easily, but when it tried to separate itself from the water it was noted that great sheets, about three-eighths of an inch thick, and something like 18 inches in height, as I remember, were climbing up the sides and actually physically dragging the ship-shaped body of the float back into the water.

After a great many changes were made in the machine I went from Hammondsport to Washington and visited Admiral Taylor at his house in the evening and talked the matter over with him, and Mr. Richardson was dispatched to Hammondsport to direct experiments following such suggestions as were settled upon by the naval constructors.

It was found, after a number of changes, that the bottom, brought out very thin on the two sides, and flaring beyond the sides of the boat, could be made to break away, *i. e.*, to separate the boat from the water and allow it to rise.

The result of Mr. Richardson's tests has shown that the rectangular floats are best and

separate most easily from the water, but the difficulty, which he has touched upon here, is that they are not suitable at all for rough water.

This whole subject of aeroplanes is a very live one, and we are going to do a great deal of flying. There being so much water on the face of the globe, and the water always being perfectly level, it constitutes the natural place upon which to alight if this one proposition that Mr. Richardson has treated of here can be solved.

A great deal of work has been done in England by the Admiralty, and within the last few weeks we have learned from very direct sources regarding the valuable work of Lieutenant Port, who was over here and who has been continuously at work on this problem in England. He has finally succeeded in designing a boat that will cope with the roughness of the waters (you remember that, practically speaking, they have nothing else over there but rough water) and that will separate itself from the water and rise with considerable ease. It is certainly very necessary that this problem be solved, and the best that we can all do together is none too good.

When the Naval Advisory Board about two months ago were taken to the Southern Proving Grounds, they were given an exhibition of a flying boat that was launched from the North Carolina. The water was rather rough at the time—it was stated afterward that it was about as rough as it had ever been—when a flight was undertaken by our flying corps, and that flight was very successful, although there was apparently some difficulty in getting off. Still, there was possibly greater difficulty in alighting on the rough water. Care had to be taken to create a lee, and the aircraft came around and alighted on the water in the lee of the big ship. Otherwise, probably it would have been very difficult for the aeroplane to have alighted at all.

We are maintaining a hangar and have been flying with hydro-aeroplanes for upwards of three years. We are flying today. We are located on the Great South Bay, which is very shallow, where we have probably about as smooth water as there is in this vicinity; but I want to emphasize, before sitting down, that if any of us can contribute to this point of getting a successful hydro-aeroplane boat, or a framework which will more easily part and separate from the water, and still be seaworthy, a very great advance will be made.

The President:—Is there any other gentleman who wishes to discuss the paper? If not, on your behalf I will express our thanks to the author of this paper.

We will now proceed to paper No. 5, entitled, "The Power Forging of Chain Cables," by Naval Constructor F. G. Coburn, U. S. Navy, Member.

As Mr. Coburn is not present, the Secretary, Mr. Cox, will give a very brief abstract of the paper.

The Secretary:—It is very regrettable that Naval Constructor Coburn is not here, because, as you will see in looking over his paper, he has given a great deal of careful thought and study to the matter, and no doubt if he were here he could give us some interesting information other than that which is contained in the paper itself.

The paper has been printed and distributed, and I will merely read a few of the paragraphs that may seem particularly interesting.

THE POWER-FORGING OF CHAIN CABLES.

By Naval Constructor Frederic G. Coburn, U. S. N., Member.

[Read at the twenty-fourth general meeting of the Society of Naval Architects and Marine Engineers, held in New York, November 16 and 17, 1916.]

There has been developed, during the last two years, at the United States Navy Yard, Boston, Massachusetts, a power-forging process for the manufacture of chain cables which has been highly successful; and on account of its success and of the possibilities at present in view this paper has been prepared for the information of the members of this Society. It will be remembered that a paper on chain cables was read before this Society in December, 1913, by Assistant Naval Constructor J. E. Otterson, United States Navy, his paper being a historical review of the manufacture of chain cables by hand and a statement of the efforts made up to that date to produce chain by a power process. Those who are interested are referred to Assistant Naval Constructor Otterson's paper for a discussion of the relative merits of side- and end-welded chain, the function of the stud, breaking and proof stresses, etc. This paper will deal with the progress of the yard in power-forging since the necessity for its development arose.

No great mechanical difficulty was experienced in the manufacture of chain by hand until diameters as great as 2¾ inches were reached; even that size was fairly well handled; but when the 3-inch cables were taken up, serious difficulties were encountered on account of the size of the metal, the mechanical difficulties involved, and the very hard labor required of the chainmakers' helpers. It was not only difficult to get chainmakers to make good chain; it was exceedingly difficult to get them to attain a satisfactorily high rate of production and regularity of attendance.

When the Panama Canal Commission went into the market for the guard chains for the Panama Canal, which were 3 inches in diameter, the Boston Navy Yard was the only plant that could reasonably approach the requirements of the Commission. A great part of these cables was made with open links—that is, without studs—and hence was inherently weaker than stud chain; and as the welds were not well made the ultimate breaking stresses obtained were low. Whereas 525,000 pounds ultimate breaking strength was required for stud-link chain and desired for 3-inch open-link chain, it was found necessary to reduce the requirement to 500,000 pounds and subsequently to 450,000. Private chainmakers were given contracts. Their chain was not so good as that made by the hand-welders at the Boston Navy Yard; it lacked the uniformity in shape and size of link and was not so well welded. In the photographs of Panama chain test triplets, to which reference is now invited, it will be seen how irregular in shape the hand-welded links were, how they were reduced in diameter next to the weld, and how obviously inferior they are to the

power-welded links. Yet they were submitted as test triplets by a private manufacturer. The hand-welded triplet No. 2 failed at 364,000 pounds; No. 1, at 390,000 pounds; but the power-welded triplet, No. 3, went to 532,000 pounds before failure. One power-welded triplet went to 586,000 pounds without breaking and was then removed from the machine for exhibition (Figs. 1 to 7, Plates 35 to 38, inclusive).

DEFICIENCIES OF HAND-WELDED CHAIN.

The causes of the inferiority of hand-made welds become apparent after experience in the testing pit. The helpers cannot hit hard enough with their sledges to drive the two scarfs together. The welding surfaces are not smooth, because they are formed by peening; pockets are thus formed, which retain slag; and the hammering does not work out this slag. Thus the weld is incomplete. Sometimes a pocket as big as a half-dollar is found, occasionally open to the sea by a small crevice. Fractures have been produced in proofing old chain which showed that not over 10 per cent of the surfaces was welded; only the strength due to form, assisted by the tacking together of the scarfs, had held those links intact in service.

In the large chain it was impossible to finish the inside of the link at the welded end, thus leaving a hollow and reducing the sectional area.

Another serious defect in the hand-welded chain is the wasting of the material, in the fire, just back of the weld. There is no way to make this up, except to increase (uniformly) the diameter of the metal in order to have the full diameter in this quarter. In the power-forged link, however, the metal is upset slightly before scarfing, completely avoiding this deficiency.

To sum up, the hand-made welds are not complete, not uniform, and not reliable.

As stated above, the need of a power-forging process had been foreseen at the Boston Navy Yard. Naval Constructor E. F. Eggert, United States Navy, had some years ago prevailed upon the master shipsmith, Mr. William Paul, to attempt the development, with the results given in Assistant Naval Constructor Otterson's paper.

The first attempt was made with a Bradley helve hammer, because that hammer hits a rapid, elastic blow, which appeared to simulate the blows of the hand sledge. That method was found impracticable, and resort was then had to ordinary steam hammers. All the experiments had been made on the 3-inch size, and at the time referred to there were available the dies that had been made for the purpose. Briefly, the process consisted of shearing the bolt to length as usual for the hand-welders, in a large power shears; bending up the end of the bolt in a 6-inch Ajax upsetting machine; putting on the scarf in a 2,500-pound steam drop hammer; bending the link by hand around a mandrel; welding the link under a 350-pound single-frame steam-forging hammer; and then, in another heat, finishing the link under dies fitted to a 3,000-pound double-frame forging hammer; trimming off the "flash" by hand.

While this process made chain that looked good, it would not meet the breaking stress requirements.

HEAT TREATMENT THE SOLUTION.

When the matter was taken up in July, 1914, this was the status. It was found, however, that no very considerable amount of chain had been made by this process; so the master shipsmith was instructed to set up his dies and start out as if to make chain, with the idea that possibly a little practice might bring the quality of the chain up to requirements. This was done. However, the breaks were still below requirements, the fracture in every case occurring in the welded quarter of the link and showing rather coarse granular structure.

At a loss to explain the matter, since the welds seemed to be good, and the hammering on the link appeared to make a better link than a hand-welder could make, consideration was given to the possible benefits of heat treatment. It was found then that there was no literature on the heat treatment of wrought iron. The iron in use had a carbon content of about 0.10 per cent, which is not much below that of dead soft steel; but again, no literature on the heat treatment of low carbon steel could be found. Nor was the shop equipped for accurate experimental heat treatment. However, a way was found to heat treat one or two test triplets, and it was found that, even though the carbon content was so low, the iron was very responsive, and that heat treatment made good chain.

It had been suggested by one or two experts who had been consulted that the chain be quenched from a temperature above the critical point, and, if possible, vibrated, this being recommended with a view to stiffening and strengthening it. The opposite kind of treatment, however, was that which was found to be successful. The reason is that the severe hammering applied to the link by the steam hammer stiffens it in the welded quarter, and a partial annealing is required to soften it enough to make the quarters deform under the shearing stress which obtains there. This permits the total stress to run up until a fracture can be obtained by a combination of shear and tension. The practice now is to give the chain an air quench from a temperature slightly above the upper critical point.

The hand-welders had not been successful with the open-link chain. The breaking stress requirement for the stud-link chain was 500,000 pounds. The open-link chain required for the Panama Canal could not be brought up to that standard, and the inspector had been accustomed to pass chain that broke as high as 450,000 pounds; but it was shortly found that by the power-forging process, with heat treatment, the open-link chain could be made to stand stresses as high as 550,000 and 560,000 pounds.

The experiments being thus successful, authority was given by the Panama Canal Commission, July 30, 1914, and the Navy Department, Bureau of Construction and Repair, July 31, 1914, to proceed with the power-forging process of manufacturing chain.

The equipment in use was, of course, more or less improvised; and during the past two years there has been a constant, almost daily, development in the equipment and its use. New hammers, especially designed for this service, have been purchased, and have proved highly satisfactory in service. The methods of heat treatment have

been vastly improved. Standard thermocouples have been manufactured and installed; potentiometers purchased, to use instead of galvanometers; and the use of the equipment studied, with the result that in the large, car-bottom, over-fired, chain-annealing furnace, where finished chain is treated, nine thermocouples are installed, and it is found practicable to keep the temperature variation, between different parts of the furnace chambers, within 10° C.

NOW ON MANUFACTURING BASIS.

During the fiscal year ending June 30, 1916, there were manufactured at the Boston Navy Yard practically 9 miles of chain, of diameters 2¼ inches to 3⅜ inches, inclusive. No better confirmation of the statement that the problem has been solved can be asked for. The cost of 3¼-inch chain, for example, has been practically $6.00 per foot, or $0.06 per pound. Even this cost is considered high, because the process is not yet wholly beyond the experimental stage; that is to say, that a very great improvement will be made, probably in the near future, in the methods of bending the link, in trimming the link after welding, and in other directions, so that the cost will shortly recede to a considerable extent. Even if the cost were greater for properly made and welded chain, it would be offset by the gain in amount and regularity of production, and in quality. Taking the case of 3¼-inch chain, for example; when the 3¼-inch iron for the Pennsylvania cables was first delivered to the Boston Yard—those being the first 3¼-inch cables made—two chainmakers' gangs were assigned the job of making a test triplet each. Each gang took a whole day to make its triplet, and laid off the next day, claiming that they had worked so hard that they were incapacitated and required a day's rest. It was stated that a production of three links in two days for one gang would be about the best that could be expected of hand-welders. At that rate it would take a single gang seven years to make the cables for a battleship of the Pennsylvania class. The present production is at the rate of twenty links per welding gang per day, every day. Were the hand-welding process still in vogue at the Charlestown Navy Yard, a shop of approximately four times the area at present engaged in chainmaking would be required in order to equal the rate of production now obtained. This estimate is in proportion to the difference in production, which takes into account the difference in space requirements for the hand-welders and for the power-welders. Figs. 8 and 9, Plates 38 and 39, give two views of a test triplet of 3¼-inch stud chain. The required ultimate strength is 612,000 pounds, which is uniformly exceeded.

When the 3-inch open-link chain for the Panama Canal was being manufactured, the cost per link, direct labor, ran about $1.37 by hand, and about $1.20 by power. The job was wound up so quickly that there was not time to bring about cost reductions, but on 3-inch stud-link chain made for the Commission, the figure of $0.86 was attained. This was subsequently still further reduced.

A brief description of the process follows, illustrated by photographs of the machines and their operations.

SHEARING THE BOLT.

The first operation is that of shearing the bar iron into lengths, or bolts, one bolt for each link (Fig. 10, Plate 40). These bolts, after shearing, are put in steel baskets, so that they can be transported by crane. The bar iron itself, when delivered into the shop, is placed on skids at the height of the bottom of the sheer blade, so as to reduce the labor involved in cutting it up. Where five or six men were formerly employed to hold up the bolt while one operated the shear, one now does all the work; and instead of having to truck the bolts two or three at a time to the upsetting machine, they are now carried in these baskets a ton or more at a time by the overhead electric traveling crane.

SCARFING THE FORGED BOLT.

The next process is that of upsetting and scarfing. Two special furnaces were built for this process, and so installed as to put a furnace, an upsetting machine, and a drop hammer practically in the arc of a circle. It was intended to have the trimming press for the scarfing operation in this circle, but it was impossible to do so without making extensive alterations, which up to the present time have not been practicable.

The furnace is charged with from six to twelve bolts, depending upon their diameter. When heated for a length of about one foot, the bolt is placed in the upsetting machine; when the treadle is depressed the cheek-blocks come up and hold the shank of the bolt, and then the header comes up and upsets it. The appearance of the bolt is then as indicated in Fig. 11, Plate 41.

In the same heat the bolt is taken directly from the upsetting machine to the 2,500-pound steam drop hammer, where the scarf is put on it. The appearance of the bolt after this operation is shown in Fig. 12, Plate 42, immediately after which it is taken to the trimming press and the flash from the drop forging removed. The other end of the bolt is then put in the furnace, with the view of scarfing it in the same way as the first end was scarfed.

BENDING THE BOLT.

The scarfed bolt is then placed in a basket similar to the one in which the bolts were brought to the drop-forge plant, and the basket when filled is carried by the overhead crane to the link-bending plant. This plant consists of a 100-ton hydraulic forging press. The press has three capacities—40 tons, 60 tons, and 100 tons. Ordinarily only the 40-ton cylinder is used. The process of bending the link is illustrated in Figs. 13, 14, Plates 43, 44. The press is of the bulldozer type, so commonly seen in railroad forging shops, and was purchased with a view to using it for bending links and other hydraulic forging purposes.

The mechanism for bending the link was designed and developed at this yard. It is mounted on a sole piece, which is bolted to the bed of the press. It consists of

a stationary mandrel of the size and shape of the inside of the bent link. The bolt is clamped into the press with one of the scarfed ends fitting one end of the mandrel snugly, as shown in Fig. 13, Plate 43. When the press comes forward, the small wheel shown in the figure as nearly touching the link simply wipes the bolt around the mandrel, leaving it in the position shown in Fig. 14, Plate 44. This small wheel is on an arbor which it attached to a toothed wheel revolving about the geometrical center of the mandrel. This toothed wheel is rotated by a sector which rotates about an arbor fixed to the sole piece of the mechanism, being pushed and pulled by a link secured to its end and to the head of the press. As soon as the chain link has been wiped around the mandrel, the scarfs are pried apart by a man with a crowbar.

WELDING THE LINK.

The description of the process of welding the link begins at the completion of a link in the chain. Immediately thereafter a helper brings a link from a preheating furnace—that is, a furnace in which the scarfed and bent link has been brought to a bright red heat—and threads it into the last link made, as indicated in Fig. 15, Plate 45. The chain being made is carried on a low jib crane with a trough running from the end of the jib to a point on the mast about 4 feet from the ground. This crane is very easy to slew, and handles the chain in a very satisfactory manner indeed. The matter of the development of a suitable crane was one of the knottiest problems, peculiarly enough, that had to be solved.

The new link having been threaded in, the crane is swung over to the large hammer. Here it should be said that each welding plant consists of two hammers, and the plant in the photograph, which was the first plant used at this yard, consists of a 3,000-pound double-frame steam-forging hammer, and a 350-pound single-frame steam-forging hammer, both hammers being operated, however, by compressed air. The 3,000-pound hammer is fitted with dies similar to drop-forging dies, in which there is an impression of the shape of the link. It should be noted that this is not the shape of the completed link; its shape has to be such that when the link is stretched to proof stress in the testing pit it will take the shape specified on the standard plan.

It is to these dies that the threaded link is brought, and the link, which has been spread apart at the hydraulic press enough to permit of threading it, is closed down. The crane is then swung over until it plumbs the fire, and the link is lowered into the fire for the first welding heat.

The oil forge used is of the ordinary type, except that it has an unusually large area of flame duct and combustion chamber, in order to reduce as much as possible the velocity of the gases, as it was found early in the development of the process that small areas with high velocities caused localized heating and serious wasting of stock.

The mechanic watches the link and feels it occasionally with a pricker, and, when hot enough, the members of the gang go to their stations. One man is sta-

tioned to operate the hammers. As only one hammer need be operated at one time, one hammer runner is sufficient. One man operates the hoist and swings the crane. The mechanic and his principal helper grab the link with a special pair of tongs, and the fifth member of the gang tends the fire, helps with the chain under the hammer, helps swing the crane, and assists in setting the stud.

When the link comes out of the fire it is swung over to the 350-pound hammer, which is fitted with special dies with horns on them, these being called "dolly dies." Under this small hammer the scarf is thoroughly hammered in such a way as to work out the slag from between the welding surfaces, and to make as thorough a weld as is possible. Experiments indicate that this is the most important process of the welding, although it has also been indicated by experiments that it alone does not suffice. Fig. 16, Plate 46, shows the link on the beck of the dolly die after this welding process. It is then very thoroughly welded, but is not in perfect shape. It is, therefore, swung back into the fire, and when again at welding heat is put in the dies of the 3,000-pound hammer and struck several times on both sides. This forms the link perfectly and completes the welding, being especially valuable in making the tips of the scarfs stick. Fig. 17, Plate 47, illustrates the link after this second welding operation.

TRIMMING.

This welding process leaves a flash, both on the inside and outside of the link, and this flash is cut off by the use of a hot chisel struck by two of the helpers in the gang.

SETTING THE STUD.

The operation of setting the stud is such a simple one that it scarcely needs description. The link is swung over to the 3,000-pound hammer, is put between the dies, standing on its side, the stud is gripped in a pair of tongs and held while the hammer pushes the link together enough to grab the stud.

THE NEW WELDING PLANTS.

The plant illustrated in the above-mentioned figures is the one on which the process was developed. It is still being kept at work, manufacturing 3¼-inch chain.

Each of the new plants consists of one double-frame 1,800-pound steam-drop hammer, to take the place of the 3,000-pound hammer illustrated in the figures, and on each side of this hammer is a 250-pound single-frame forging hammer, one being left-handed, the other right-handed. The dies under the 250-pound hammers are similar to those shown on the 350-pound hammer. The dies under the 1,800-pound hammer are like those shown for the 3,000-pound hammer, being fitted with impressions on both sides. Thus the arrangement is such that one gang may work on one side of the 1,800-pound hammer and another gang on the other side, each having its own crane, fire, and 250-pound hammer, and dividing the cost of the 1,800-pound hammer between them. One of these plants is illustrated in Fig. 18, Plate 48.

ECONOMIC IMPLICATIONS OF THIS DEVELOPMENT.

It is interesting to note the economic significance of this power-forging process of making chain, as it is an excellent illustration of the division of labor which always results in the application of power for operation. Where one gang performed the operations of scarfing, bending, welding, finishing, etc., it was impossible to substitute a machine for the gang. But when the process was divided into its integral parts, then it was found that each little part was a simple one, to be done over and over again, and lending itself to the application of power. It has also this significance—that where the hand-welding process required a high-grade mechanic on each operation, this process required a high-grade mechanic on only one operation —that of welding; the other operations are so simple that a helper can be used, the helper being carefully taught the particular part of the process that he will have to perform. For example, the shearing of the bar is done by a helper; also, the bending of the links is done by helpers; the upsetting and scarfing operations are performed by fourth-class mechanics who were helpers and who have been trained to do this particular work. They were rated from helpers because the work is somewhat above that which would be normally expected of a helper.

DEVELOPMENT OF EQUIPMENT AND MEN NECESSARY.

The 3,000-pound forging hammer and the 350-pound forging hammer shown as used in the manufacture of 3¼-inch chain were standard forge-shop equipment; but their limitations were discovered at an early date. The welding process required a self-contained hammer, in order that the dies may always be in alignment. The standard types of drop hammers are not satisfactory, because there is not sufficient width between the legs. It was therefore necessary to obtain special drop hammers, made up with the frame of a forging hammer, the cylinder and top tie plate of the drop hammer, and a special anvil like that of a drop hammer, only wider and lighter. The falling weight was made as small as practicable for a machine of the size required. The special drop hammer, used for the second process of welding, is shown in the final figure of the series. The small hammer is a 250-pound forging hammer, with a special frame, giving unusual height and clearance between the center of the piston rod and the inside of the frame. For this, also, the falling weight was made as small as practicable. Similarly, the cranes used to handle the chain were especially designed. It is not only necessary to handle the link when it is being welded; the chain already made must be taken care of. The duty required of the air hoists on these cranes is very exacting.

All the experimental work was done with cast-iron dies, because cast-iron dies are cheap and could be readily made from molds of the shapes desired to be forged, and as experimental work went along new and improved dies could be furnished promptly, the success of this work being due to the ingenuity of the master shipsmith, Mr. Paul. All the early dies, of course, were made by "rule of thumb" and by a process of trial and error. There was a continual process of trying and fixing dies go-

ing on, and the development was necessarily delayed by broken cast-iron dies, etc. As the art progressed, it was taken out of the "rule of thumb" class and put on an engineering basis, for which the credit goes to Mr. W. B. Bradford, in charge of the plant draughting.

Steel dies were then put in service. Experimental comparison was made of cut dies versus cast-steel dies, in which contest the latter won, being cheaper and lasting quite as well. At the time this paper was written a pair of cast-steel dies had been in service twenty-four hours per day for almost every working day over a period of eleven months and they are still in good condition.

When the design of the dies was put on an engineering basis, the work was greatly simplified. At present, if a new size of chain is to be made, the dies are all designed in the drawing office, the designs sent to the pattern shop, patterns made, the dies cast and machined, and when put in the hammers produce chain which meets test requirements. In the early part of July, 1916, the Bureau of Construction and Repair inquired whether 3½-inch chain cable could be made if required for the new capital ships, and the yard was able to reply by return mail that this large cable could be made without difficulty.

The development of equipment—hammers, dies, etc.—was no less difficult than the development of skilled help. As the process was begun at a time when the chainmakers were on strike, the services of shipsmiths and blacksmiths were requisitioned, on account of their knowledge of the use of hammers. The extraordinary shortage of skilled labor, brought about by the business conditions in the country during the time when this process was being developed, made it necessary to use all obtainable shipsmiths on regular shipsmithing work, and it early became necessary to make mechanics out of unskilled material. The scarfing process requires drop forgers. It has been found to be no great task to make a good enough drop forger out of any reasonably intelligent helper; it has also been found that men could be graduated from this work to regular drop-forging work without difficulty, and some eight or ten skilled drop forgers were thus developed to make the studs required for the chain. In a similar manner helpers were trained to the other operations of the process, until at present the skilled mechanics are all recruited from the force of helpers. There are always a number of helpers anxious to learn the business, and the practice is made of keeping one or two on hand, ready to step to the fire in case of defection of any regular operator. This has been one of the great advantages, from an operating viewpoint, of the new process.

DISCUSSION.

The President:—Does any one desire to discuss this paper by Mr. Coburn on "The Power Forging of Chain Cables?"

Naval Constructor W. J. Baxter, U. S. Navy (Communicated):—The responsibility for the origin and development of this power forging process of making large chain,

after approval of the Navy Department, has been mine; but too much credit cannot be given to the author of this paper and the men named therein; also to the author of the paper of two years ago, Mr. J. E. Otterson, describing the earlier developments of this process, which he initiated. They have all worked together in true workmanlike spirit, perfecting details, insuring better results each year, and reducing costs.

This process was begun under peculiarly unusual circumstances, but it has been increasingly successful. There is nothing patented or secretive about it, and any good smith can be readily trained to produce, at much less discomfort to himself than he now experiences, chain which is true to size and which meets all strength requirements, if the bar iron from which it is made conforms to its specifications and the proper tools are provided.

In the development of our merchant marine large quantities of chain cable will be necessary; possibly this new naval method of making chain will aid in securing it more rapidly. If more detailed information is desired, I do not doubt that the Navy Department will permit personal observation of the methods used, and which are continually improving, because private shipyards have not been chary in furnishing detailed information concerning their methods of building ships by the so-called "Universal method."

The Boston yard is now successfully carrying out this shipbuilding system to an extent which is not yet fully appreciated, but it obtained its results from following private practice. Shipbuilding is not a hidden art, and we, as a Society, exist to broaden it.

I much regret that urgent work prevents my being with you today, and following up the discussion on this interesting portion of our work on ships.

Naval Constructor F. G. Coburn, U. S. Navy (Communicated) :—As suggested by Naval Constructor Baxter in his discussion, the new process is the product of many minds and no one person is responsible for it. One of the important factors was the support given by Captain (now Vice-Admiral) D. W. Coffman, U. S. Navy, then Commandant of the Navy Yard, and to whom Naval Constructor Baxter was responsible. It was largely due to Captain Coffman's firmness and prompt decisions, in a very trying labor situation, that the new process got under way so promptly.

The President:—Is there any other discussion on this paper?

If no one else desires to discuss the paper I will, on behalf of the Society, extend its thanks to the author.

A number of shipbuilders and their associates have been called to Washington to discuss the building of the new naval ships. That accounts for the absence of many of these members this morning, but I presume they will be here tomorrow.

We have three papers yet to be read, and it is proposed to leave them for the afternoon session. When we adjourn, it will be for luncheon, to meet again at half past one o'clock. We will then take up the three papers, and following them will be an illustrated talk on submarines by Mr. E. H. Ewertz. That is expected about half past three.

If there is nothing further to bring before the meeting at this time, a motion to adjourn will be in order.

SECOND SESSION.

THURSDAY AFTERNOON, NOVEMBER 16, 1916.

President Taylor called the meeting to order at 1.50 p.m.

THE PRESIDENT:—We will resume the sittings of the day, gentlemen, by the reading of paper No. 6, entitled "Description and Trials of the Turbine Steam Yacht Winchester," by Mr. E. A. Stevens, Jr., Member. Mr. Stevens, unfortunately, is on the Pacific coast, but Secretary Cox will try to give you a brief résumé of the paper.

THE SECRETARY:—It is much to be regretted that the author of this paper is not here to present it in person, as he has taken a great deal of pains in assembling the information. Unfortunately he was called to the Pacific coast before the paper was really completed and was, therefore, unable to insert in the paper his analysis of the trial results, with particular reference to the propeller performance, as analyzed by Captain Dyson's method.

The author has promised to supply this additional information so that it may be incorporated in the paper when it is finally printed and bound in the Transactions of the Society.

As the author has pointed out, the Winchester is the fourth vessel of the same name built for the same owner. It is, however, very different from the preceding yachts of the same name, in that, although she has extreme speed, the cruising accommodations and seagoing characteristics have not been neglected.

At first sight an inspection of the plans would indicate that a large amount of space was given to the machinery, and that the owner's accommodations were relatively small. Upon comparing the general arrangement, however, with the plans of other so-called fast yachts, it will be seen that Mr. Rouss in this vessel has unusually good accommodations for a vessel of this type. In the average high-speed yacht, the owner in establishing the dimensions has insisted upon a certain speed and has accepted such accommodations as could be arranged. Mr. Rouss, however, had a definite amount of accommodation that he wished to secure; he stipulated the speed that he would expect, and left the dimensions of the yacht to the designers, thus allowing them to produce a boat having the comfort that was required, and in other respects producing a satisfactory proposition from an engineering point of view.

An examination of the table showing the relative dimensions and characteristics of the four Winchesters indicates that the owner's ideas as to size and speed have been continually increasing. It may be said, however, that in the present Winchester Mr. Rouss seems to feel that he has gone as far as is necessary in either direction.

The secretary then abstracted the paper.

DESCRIPTION AND TRIAL OF THE TURBINE STEAM YACHT WINCHESTER.

By E. A. Stevens, Jr., Esq., Member.

[Read at the twenty-fourth general meeting of the Society of Naval Architects and Marine Engineers, held in New York, November 16 and 17, 1916.]

The steam yacht Winchester is the fourth vessel built for Mr. P. W. Rouss to bear that name. Like all her predecessors she was built primarily for speed but is considerably larger than her predecessors; in fact, she is the largest high-speed steam yacht ever built.

The Winchester is a twin-screw vessel, fitted with Parsons turbines and designed for a speed of 29 knots at about 360 tons displacement, with the main engines developing about 7,000 shaft horse-power. The vessel was built by the Bath Iron Works, of Bath, Me., from designs furnished by Cox & Stevens, of New York City.

Hull Data.

Length overall	225′	0″
Length, load-water line	224	0
Beam, extreme	21	0
Beam, load-water line	20	8
Draught on trial	4	11¾
Displacement on trial	322	tons

The hull is built of high tensile galvanized steel of substantial scantling, her plating is 11 pounds amidship to 8 pounds at the ends, the shear strake from 13½ pounds to 8 pounds, while the keel is from 12 pounds to 10 pounds. The frames are correspondingly heavy, spaced 21 inches apart. From the above it can be seen that although high speed was desired, strength was not sacrificed. She has been given several severe tests last summer and has yet to show a weak place. She has also proven herself to be very able, as well as comfortable, in a seaway.

Accommodations.—As can be seen from the plans, she has plenty of accommodation for both owner and crew, in spite of the large space given up to engines and boilers.

On the main deck forward, under the raised forecastle, is a large locker for the bos'n stores, etc.; aft of which are the officers' quarters, consisting of the bathroom, mates' and captain's staterooms on the starboard side and the chief engineer's and assistant engineer's rooms on the port. Next comes the officers' messroom, aft of which is the pantry, both extending almost the full width of the ship, there being a passage on the port side. The owner's dining saloon is in the forward deck-house, the top of which is an extension of the forecastle deck.

In the after deck-house is a large lounge for the owner and guests.

On the berth deck forward is the forecastle, next to which on the starboard side are staterooms for the steward and waiter, cook and mess boy; on the port side are a toilet, store-room and ice-box, and aft of these is the galley, extending the full width of the vessel.

Aft of the machinery space and fuel oil-tanks are the owner's and guests' quarters consisting of two large staterooms extending the full width of the ship, four smaller rooms, a lobby on the port side, two bathrooms and two toilets.

Boats.—The following boats are provided and carried on davits:—One 26-foot motor launch for owner, one 25-foot working motor launch, one 16-foot dinghy.

Crew.—The crew consists of captain, mate, chief engineer, assistant engineer, steward, cook, cabin boy, mess boy, four sailors and three firemen.

Boilers.—The boiler equipment consists of two Normand water-tube, express-type boilers with 8,184 square feet total heating surface and each fitted with eight oil burners of the mechanical atomizing type. The maximum pressure allowed is 260 pounds per square inch, although this pressure is never used, 31½ knots being obtained with only 225 pounds at the high pressure turbine.

Main Engines.—The propelling machinery consists of Parsons turbines arranged on two shafts, the high-pressure turbine being on the starboard while the low-pressure with the astern turbine is on the port shaft. These were designed for 7,000 shaft horse-power at 900 revolutions per minute and are of the following dimensions:—

	H. P. turbine, inches	*L. P. turbine, inches*
Length of rotor	82	57 9/16
Diameter of rotor	32	42
Rows of moving blades	54	26

The thrust bearings are forward of the turbines and are of the Parsons type.

Main Condenser.—There is one main condenser of 4,163 square feet cooling surface. The construction is similar to those that have been put into destroyers built by the Bath Iron Works. The section is circular and contains 2,832 ⅝-inch tubes. The tubes are bent to a curve to allow for expansion, and the ends are rolled into the tube sheets, which are not parallel. A vacuum augmentor of the Parsons type is also provided.

Propellers.—There is one three-bladed outboard turning propeller on each shaft. These are of manganese bronze cast solid. The blades are true screws, machined to pitch, and polished. The following are their dimensions:—

Diameter	55 inches.
Pitch	51 inches.
Projected area	1,422 square inches.
Projected area ÷ disk area	.60

Pumps.—The various pumps are shown in the following table:—

No.	Pump	Make and type	Size
1.....	Main air.....	Warren.....	10″ × 22″ × 16″
1.....	Main feed.....	Warren Simplex	13″ × 9″ × 14″
1.....	Auxiliary feed	Warren Simplex.....	13″ × 9″ × 14″
1.....	Main circulating.....	Centrifugal 12″ suction and discharge engine...	7″ × 5″
1.....	Fore and bilge.....	Warren Simplex.....	4½″ × 5½″ × 6″
2.....	Lubricating oil.....	Warren Simplex	2½″ × 4″ × 6″
2.....	Fuel oil.....	Warren Duplex.....	4½″ × 3″ × 12″
1.....	Fresh water	Centrifugal driven by electric motor	
1.....	Salt water	Centrifugal driven by electric motor	
1.....	Sanitary	Warren Simplex	3½″ × 5″ × 6″

Other Auxiliaries.—The other auxiliaries consist of the following:—

Feedwater heater of 248 square feet.

Fuel oil heater, 75 square feet.

Lubricating oil cooler, 63 square feet.

Two forced-draft blowers driven by Terry turbines.

Electric outfit consisting of a 10-kilowatt direct-current generator driven by a Curtiss turbine.

A special type of steering engine made by the Hyde Windlass Company, with two cylinders, each 4 inches by 4 inches.

A Hyde steam windlass with two cylinders, each 4 inches by 4 inches.

Trials.—The trials were run, in smooth water, over the government course off Rockland, Me. Twelve runs in all were made with the following results:—

Run	Direction	R.P.M. mean	Estimated S.H.P.	Speed in knots	Run	Direction	R.P.M. mean	Estimated S.H.P.	Speed in knots
1.....	N	1014.5	7020	30.38	7.....	N	713	3272	23.92
2.....	S	1031.0	7360	32.11	8.....	S	697	3194	24.83
3.....	N	1032.5	7580	30.98	9.....	N	497	1155	17.22
4.....	S	1035.0	7485	32.09	10.....	S	540	1320	19.87
5.....	N	1035.5	7360	30.90	11.....	N	295	269	10.21
6.....	S	1038.0	7470	32.32	12.....	S	287.5	206	11.21

After the progressive trials a two-hour run was made, on which the oil consumption was measured by sounding the fuel oil tanks. The speed obtained was 19.7 knots and the oil consumed was 669 gallons. Taking the shaft horse-power from the curves at 1,510 and assuming a specific gravity of .88 for the oil, this would give about 1.625 pounds of fuel oil per shaft horse-power per hour.

I would like to call attention to the picture (Plate 52) which was taken during one of the high-speed runs. The bow wave here is not very high and consists of a very thin sheet of water, as the painted water-line on the ship's sides can be plainly seen through it. The trim of the vessel at this speed is changed very little from that at rest. Had more power been supplied, no difficulty would have been experienced in obtaining very much higher speed; this is substantiated by the tank trials of the model.

It might be of interest to compare the preceding Winchester with the present one, which is best done by looking over the following table:—

	Winchester No. 1	Winchester No. 2	Winchester No. 3	Winchester No. 4
Present name	Adroit	Flying Fox	.....	Winchester
L.W.L.	140′ 0″	165′ 0″	205′ 0″	224′ 0″
Beam	15′ 6″	16′ 0″	18′ 6″	21′ 0″
Trial draught	5′ 0″	3′10¾″	3′11½″	4′11¾″
Trial displacement	150 tons	136.3 tons	207.5 tons	322 tons
Machinery	Reciprocating	Parson's turbines	Parson's turbines	Parson's turbines
Number of propellers	2	3	2	2
Horse-power	About 1500 I.H.P.	About 3000 S.H.P.	About 7000 S.H.P.	8074 S.H.P.
Speed	About 20 knots	26.516 knots	32.24	31.56

APPENDIX.

From the curves on Plate 55 it will be noticed that the propulsive coefficients are rather high, especially at the lower speeds. On this account, the writer thought that it would be of interest to analyze the propellers by Dyson's method, as published by Lieut. S. M. Robinson, U. S. Navy, in the Journal of American Society of Naval Engineers, Vol. XXVIII, No. 4, November, 1916. The calculations are as follows:—

Slip B.C. $=.375$

$PA \div DA = .60$

Pitch $=4.25$

Diameter $=4.58$

T.S. $=13{,}550$

$R - TS \div \pi D = 942$

$P \times R = 4{,}000$

$IT\alpha = 11.94$

$1 - S = .786$

$$V = \frac{P \times R \times (1-S)}{101.33} = 31.00$$

$N = 2$

$$\text{I.H.P.} = \frac{N \times D^2 \times 1\,Td \times (P \times R)}{291.8} = 6{,}860$$

P.C. $=.525$

E.H.P. $=$ I.H.P. $\times PC = 3{,}605$

$$\text{S.H.P}d = \frac{\text{I.H.P.} \times .92}{10^2}$$

$$s = \frac{S \times K \times V^{3-x}}{10^2 \times v^{3-x}}$$

e.h.p. / E.H.P.	e.h.p.	v	10^2	S.H.P.d	S.H.P. from curve	v^{3-x}	S	v^{3-x}	s	$1-s$	Rd	R from curve
1.2	4330	31.5	.827	7640	7430	21540	.215	22200	.252	.748	1008	1030
1.1	3967	30.4	.905	6980	6690	21540	.215	20780	.246	.754	962	972
1.0	3605	29.24	1.00	6310	5955	21540	.215	19300	.240	.760	924	912
.9	3245	28.06	1.116	5660	5240	21540	.215	17600	.235	.765	876	854
.8	2885	26.87	1.262	5000	4535	21540	.215	16000	.229	.771	830	801
.7	2525	25.63	1.450	4350	3850	21540	.215	14400	.222	.778	785	752
.6	2163	24.35	1.702	3710	3210	21540	.215	12700	.214	.786	740	704
.5	1803	22.98	2.058	3065	2610	21540	.215	11000	.205	.795	690	656
.4	1443	21.47	2.597	2430	2035	21540	.215	9230	.193	.807	635	607
.3	1082	19.76	3.504	1800	1530	21540	.215	7300	.181	.819	576	555

DISCUSSION.

Mr. Ernest H. B. Anderson, *Member:*—I should like to make a few remarks regarding the design of this yacht. As Secretary Cox points out, she is a remarkable vessel in many ways, and the designers and builders deserve the greatest praise.

As regards the machinery, the aim of the builders was to produce an installation combining extreme simplicity and ruggedness without sacrificing, in any way, essential features. Few auxiliaries are actually needed for propelling the vessel; the circulating water from the sea for condensing the exhaust steam is forced through the condenser by scoop circulation, which eliminates this pump and its engine when the vessel is under way. The two forced draft blowers are arranged in series which effects a considerable saving in steam consumption; the usual practice in vessels of similar type is to have live steam connections to each blower, so the saving in steam is approximately one-half.

The reason for the two-hour trial run in the open sea at approximately 20 knots was to determine the cruising radius of the vessel at this speed, and I think the result showed that she could steam about 2,000 knots at this speed with the quantity of oil fuel which the tanks hold.

The simplicity of the machinery design has also resulted in a large saving in weight, and I think the value of the paper would be greatly enhanced if these figures are available, for it would then be possible to give figures of shaft horse-power developed per ton of machinery. Again, a plan view in outline showing the arrangement of the engine and boiler rooms would also be of much value, as the general arrangement plan of the vessel shows no machinery in these compartments.

Lieutenant S. M. Robinson, U. S. Navy, *Member* (Communicated) :—The following table has been made out for the Winchester using the data given by Mr. Stevens, and in it the revolutions have been calculated by using the ac ual instead of the estimated horse-powers. This table shows that up to 28 knots there is practically no error in the revolutions. From 28 knots on up to the highest power reached, the error is constantly increasing. If the values of $\frac{\text{e.h.p.}}{\text{E.H.P.}}$ and $\frac{v}{V}$ are plotted on the cavitation chart, it will be seen that the propeller was in cavitation after the 28-knot point was reached. At 31½ knots the cavitation was considerable.

The equation for the revolutions will not hold with the same accuracy for a propeller cavitating that it will for a propeller working under normal conditions. In fact, if cavitation is serious, the equation will not hold within the reasonable limit desired.

As regards the difference in estimated and actual horse-power, the same phenomenon is found in this high-speed boat that has been found in some of the destroyers. They seem to have an abnormal wake which increases the effective horse-power of the hull when it is being towed, but also increases the propulsive coefficient and consequently reduces the necessary shaft horse-power when the boat is being propelled by its screws.

V	Estimated R.P.M.	Actual R.P.M.	Per cent of error
31.5	992	1030	3.69
30.4	947	972	2.575
29.24	899	912	1.425
28.06	854	854	.000
26.87	806	801	.625
25.63	759	752	.932
24.35	707	704	.427
22.98	662	656	.915
21.47	610	607	.495
19.76	556	555	.18

Mr. Stevens (Communicated) :—I regret to say that as I am not in possession of the data referred to by Mr. Anderson, I am unable to give any information on this subject.

In answering Lieutenant Robinson's remarks, it is true that by using the actual shaft horse-power the revolutions obtained by the analysis work out much nearer the actual revolution than they do by using the estimated horse-power. However, I am not prepared to fully accept the reason stated for the discrepancies at the lower speeds, as there are several chances for errors which I will enumerate.

First, the effective horse-power with appendages was estimated by taking the bare hull estimated horse-power (from tank trials) and multiplying it by 1.09.

Secondly, the runs on the progressive trials were made (as can be seen by examining the table) as follows:—Six at top speed and only two runs at each of the following—about 24.4 knots, 18.5 knots and 10.71 knots.

Thirdly, I have been informed by the builders that the torsion meter cards at the lower powers were very small and too much reliance should not be placed upon their accurateness.

I do, however, believe that there is a large amount of truth in the reasons stated by Lieutenant Robinson, although I do not think that they are the whole cause for the differences at the lower powers.

Before closing, I wish to thank the Society for the interest taken in this paper.

The President:—Is there any further discussion? If not, I am quite sure that you will agree to my extending to Mr. Stevens the thanks of the Society for this paper.

As was called to the attention of the Society a couple of years ago, Mr. Stevens is the son of one of the founders of this Society. There are not many sons of founders at the present time who have developed as has Mr. Stevens. We are very glad indeed to hear from him.

We will now proceed to paper No. 7, entitled "Theory of Fluid Friction," by Mr. W. Gatewood, Member.

Mr. Gatewood presented the paper, and in connection therewith, said:—

"The subject of fluid friction has received attention in connection with shipbuilding, since 1869, as far as I have been able to find out, and in that year Mr. William Froude made public a theory of fluid friction in which he conceived that the velocity across the wake would vary uniformly.

"In 1872, in the report of his first classical experiments on friction planes, he made a computation of the width of the wake, using the principle of momentum in the determination, but still considering that the velocity across the wake would vary uniformly.

"A few years ago Dr. Stanton published the results of some experiments he had made with air, in which he showed the curve of variation of velocity across pipes of various sizes.

"It was this curve of Dr. Stanton's that led me to take up the subject further and prepare this paper. A cross-section of the curve of velocity did not follow exactly the parabolic law which it seemed would be theoretically correct. It rather indicated that the pressure across the section of the pipe was not uniform, but that the total head was uniform. A further consideration would show that this would be impracticable, and that somewhere in the length of a pipe, some distance from the entrance or exit, there must be a uniform pressure head in order to maintain constant conditions of flow.

"The coefficients of viscosity, which have been published, and with which I have been able to get in touch, are of such a character that I have been unable to compare them with the coefficient which is used in the paper. They seem to have been determined, not with reference to the rate of change of velocity, but with reference to some other characteristic of the fluid. It would appear that if the theory here advanced is of value, this coefficient, based on the rate of change of velocity, should be experimentally determined.

"This rate of change of velocity I have expressed in the paper as a trigonometrical function. I was advised that the proper way to describe it would be as the differential coefficient of the velocity; but it seemed to me that the general character of the paper would make it more satisfactory to treat it as a trigonometrical function than as a function of the calculus.

"Formula (2) indicates that since tan α varies as the ratio of the velocity to the linear dimension and also as the square of the velocity, if the velocity be doubled, the diameter of the pipe should be halved. That thought was first worked out on the basis that since experiments show that if the velocity were doubled, the diameter of the pipe must be halved in order to obtain the same cross-section of velocity, then the friction varied as the square of the velocity; in other words, that the formula proves backwards, if you take the experimental result as being correct.

"Most of the publications on fluid friction state a critical velocity below which the friction varies as the first power of the velocity, and above which it varies as some higher power; but it would seem to me that if it is true, that if the velocity is doubled, the diameter of the pipe must be halved to obtain the same cross-section of velocity, then that fact proves that friction varies as the square of the velocity, the equivalent velocity of rubbing on the wall of the pipe.

"By reference to Fig. 2, Plate 57, you will note that two curves are shown, one for a smooth pipe and the other for a rough pipe, and that while the coefficient of friction, according to the theory, in the case of the rough pipe would be 3.16 times as great as in the case of the smooth pipe, the resistance would be only 2¼ times as large. It would seem, then, if this is correct, that any comparison or discussion of friction based on the mean

velocity through a pipe would not lead to correct results, since for a variation in coefficient of over three times, the resistance is increased only two and one-quarter times, for the same mean velocity.

"The cuts and description relative to the flow in open channels are a little crude, but it seemed to be an intermediate step from friction in a pipe to friction in the open, to consider that part of the subject; and the method of taking the total energy or total head, as being made up of the velocity head and what I call the position head, which has to do with the height of center of gravity of the moving water—this same method of treatment for narrowing and widening channels seems to have some possibilities in connection with wave formation accompanying the motion of vessels, on which we have been trying to get some line ever since model experiments were first started.

"Curves showing the retardation of velocity and the width of wake under certain assumed values of coefficients of F and tan α indicate that the percentage of speed adjacent to the plane decreases very rapidly at first for a very small increase in length, and decreases very slowly for lengths above 1,000 feet.

"The width of the wake increases fairly rapidly for the first 300 feet, and then very much more slowly for the longer plane. One peculiar thing is indicated by the formula for the width of the wake:—According to the theory, the width of the wake decreases with the increase of velocity, and increases with the roughness of surface.

"Following equation (15), you will note that I draw some comparison as to how the width of the wake varies and how the loss of head varies. For corresponding conditions, the length varies inversely as the velocity, and the resistance varies directly as the velocity; from which, for the same fluid and the same roughness of the surface, it will be seen that for a constant value of the product of the velocity and the length, the resistance varies as the velocity.

"This fact would seem to be apparent by the experiments made on flat planes, as you will notice from Fig. 10, Plate 61, that the resistance for speed of 400 feet per minute and a length of 40 feet will be one-half the resistance at 800 feet per minute, and a length of 20 feet. The spots do not fall exactly on the experimental curves, but they do fall so closely as to indicate that this is probably a true statement of the case for the same roughness of surface and the same fluid.

"I tried to enlarge this comparison by introducing the viscosity in the formula of the product of the length times velocity, but I was unable to get a good comparison with Reynolds' number, as the viscosity coefficients do not seem to mean exactly the same as the coefficient which I have used in the paper.

"The feature of the theory which leads me to consider that it is not complete, as I have noted in the fifth item of the theory, is as there stated:—'The determination of the loss of head in the wake is complicated by the condition that the volume of the fluid passing the fixed body is not altered, although the velocity in the wake is decreased.' Neglect of that condition leads to a very serious difference between the experimental curves and the theoretical curves. In the experimental curve you will notice that after passing a length of about 30 feet the variation in resistance seems to follow almost a straight line, whereas in the theoretical curve the resistance tends to decrease at a fairly rapid rate for quite a distance longer than the 50 feet of the original experiments by Mr. Froude. If this condition may be neglected, the coefficient of friction we are using on ships would hardly be correct for long vessels. It is probable, however, that the experimental data are correct, and that

the theory will have to be adapted in some way to make allowance for the elevation of the surface which would take place in accordance with item 5 of the theory.

"Curves prepared according to the theory indicate that the resistance is continually decreasing as the length increases, and at a fairly rapid rate, although not nearly so rapidly as at the start. Using slightly different coefficients from those given in the paper, it is found that the horse-power absorbed in the friction of a 600-foot plane at 12 knots would amount to the product of the wetted surface by .0176, whereas Tideman's coefficient is about .0312, or nearly double. I think the smaller coefficient cannot be true.

A THEORY OF FLUID FRICTION.

By William Gatewood, Esq., Member.

[Read at the twenty-fourth general meeting of the Society of Naval Architects and Marine Engineers, held in New York, November 16 and 17, 1916.]

The subject of fluid friction has received a great deal of attention, and empirical formulæ are in general use in connection with the flow of water, air and other fluids in closed pipes, and with the flow of water in open channels. We have empirical formulæ also for determining the frictional resistance of vessels, derived from an analysis of experiments on flat boards. Until very recently, however, very little progress has been made in checking the accuracy of the assumptions made in extending the results of these experiments to higher speeds, greater lengths, and shipshape forms.

It seems that the reason why our knowledge of frictional resistance is so uncertain is due to the fact that there is no generally accepted theory of fluid friction. This paper is an attempt to correlate the laws of fluid motion which seem to have a bearing on the subject, and to formulate a theory.

FLOW IN PIPES.

Experiment has shown that the velocity of a fluid flowing through a pipe is not uniform across the section. When the flow is steady, the velocity is greatest at the axis of the pipe, diminishes slowly as the distance from the axis increases, and then seems to diminish rapidly in the immediate neighborhood of the wall of the pipe.

When there is a variation in velocity across the section of a fluid in steady flow, it seems reasonable to consider that the resistance offered by the slower moving fluid to the fluid which is moving faster varies directly as the rate of change in velocity.

On this hypothesis, the frictional force exerted on a central core of the fluid in a pipe by the surrounding fluid may be expressed as—

$$F \,.\, \tan \alpha \,.\, L \,.\, 2\pi R.$$

In this expression, F is a coefficient of friction which will vary with the nature and temperature of the fluid. It may be called a viscosity coefficient. Tan α is used to denote the rate of variation of velocity at the circumference of the core of fluid, and may be expressed as so many feet per second per foot of width. L is the length of the pipe and R is the radius of the core. If foot, second, pound units are used, the frictional force given by the above formula will be the force in pounds.

This force reduces the pressure head on the fluid of the core, and this loss of head in a given length of the pipe may be expressed as—

$$h_R = \frac{F \,.\, \tan \alpha \,.\, L \,.\, 2\pi R}{w \,.\, \pi R^2} \tag{1}$$

In this equation, w is the weight of a unit volume of the fluid.

After the flow in a pipe has become steady, the pressure head at any cross-section must be constant across the section. The velocity varies, however, and so the total head is not uniform across the section. The loss of pressure head in a given length will be the same for a core of any size, and it will be seen from equation (1) that for this loss of pressure head to be constant, $\tan \alpha$ must vary inversely as the radius of the core. This is a property of the common parabola, having its vertex on the axis of the pipe, and such would seem to be the curve of velocity.

If the wall of the pipe were very smooth, so that there would be no eddying adjacent to it, this curve of velocity would hold for the full diameter of the pipe. Assuming that the friction varies as the square of the velocity of the fluid adjacent to the wall of the pipe, the friction of the wall of the pipe on the fluid would be

$$f \,.\, V_p^2 \,.\, L \,.\, 2\pi R_p$$

in which f is the coefficient of friction as generally used, and V_p is the velocity adjacent to the wall. It will be seen that, when eddying is neglected, this equals the friction in the fluid at the wall of the pipe, or—

$$f \,.\, V_p^2 \,.\, L \,.\, 2\pi R_p = F \,.\, \tan \alpha_p \,.\, L \,.\, 2\pi R_p,$$

or

$$f \,.\, V_p^2 = F \,.\, \tan \alpha_p \tag{2}$$

For a similar curve of velocities across the section, it will be noticed that, if the velocity be doubled, the diameter of the pipe must be halved, since $\tan \alpha$ varies as $\frac{V}{R}$ and also as V^2. This fact has been noticed in experiments.

Near the wall of the pipe, however, the flow is not uniform, but is full of eddies, as is evidently indicated by the fact that a stationary wall, however smooth, cannot replace surrounding fluid moving at the speed suited to an extension of the curve of velocities. The curve of velocities is modified by this eddying, somewhat as indicated in dotted lines on Fig. 1, Plate 57. The total head in the region of the eddies is probably the same as if there were no eddying, since the pressure head must be the same as for the rest of the core of fluid and the energy of the eddy motion is likely to compensate for the lack of forward velocity of the fluid. The extent of the eddying would probably increase as the roughness of the surface increases, and also as the velocity increases. It may be also that the eddies keep on growing as the distance from the end of the pipe decreases, but this is hardly likely, as they may be

considered as rollers between the fast-moving core of fluid and the fixed wall of the pipe, and their size would be practically constant, for uniform flow of the core, so long as the roughness of the surface of the pipe is unchanged.

If the value of F, in equation (2), were experimentally determined for various fluids and through a range of temperature, then the loss of head in a given length of pipe of any diameter and for any velocity of flow might be determined from the value of the coefficient of friction f obtained by experiment on any size of pipe having the same roughness of surface.

If a portion of the length of the pipe is roughened, the volume of flow will be unchanged, but the curve of velocities across the section will be altered. The velocity at the axis of the pipe will be increased, and the rubbing velocity will be decreased. This is illustrated in Fig. 2, Plate 57.

FLOW IN OPEN CHANNELS.

Consider a smooth, open channel or trough of constant section and of uniform slope in which water is flowing steadily. Let y be the depth of the water and v the velocity. Suppose a portion of the length of the channel to be roughened and let Y be the depth of the water and V the velocity in this roughened length after steady motion is attained, the volume of flow being unchanged. In determining where the change in velocity occurs, we find four conditions depending on the relative value of y and v.

If any reduction in velocity causes a decrease in the total head, the change in velocity will occur on the rough surface, since the friction will be greater until the velocity has been reduced, and it is this increase in friction which causes the loss of head. The change back to the greater velocity will occur on the smooth surface, since there is a gain in total head, and the friction will be less on the smooth surface until the original velocity is acquired again (Fig. 3, Plate 58).

If any reduction in velocity causes an increase in the total head, the change in velocity will occur on the smooth surface, where the friction is less than normal. The change back to the greater velocity will occur on the rough surface, where the friction is greater than normal and absorbs the excess of head (Fig. 4, Plate 58).

If the reduction in velocity causes first a decrease and then an increase in total head, the final change being a decrease, it would appear that the whole decrease in velocity will occur on the rough surface. In order that there may be no increase in head at any stage of the change, it is probable that the surface water is retarded sooner than the bottom water, and the velocity head is greater in proportion to the depth than it would be if the velocity wer uniform from top to bottom. The change back to the greater velocity will occur partly on the rough surface, and partly on the smooth, since the increased friction on the rough surface due to the increased velocity will cause a loss of head, and then the decrease in friction on the smooth surface will cause the head to increase again (Fig 5, Plate 59).

If the reduction in velocity causes first a decrease and then an increase in total

head, the final change being an increase, it would appear that the whole decrease in velocity will occur on the smooth surface. A more rapid decrease in velocity at the surface of the water will serve to prevent the occurrence of a decrease in the head in the early stages of the change in velocity. The change back to the greater velocity will occur partly on the rough surface and partly on the smooth, as in the previous case (Fig. 6, Plate 59).

Consider an open trough of some width, with a strip of rough bottom introduced at the middle of the width. The tendency will be for the depth of the water over the rough strip to increase as its velocity decreases. This increase in depth will cause a side flow, and the depth over the smooth bottom adjacent to the rough strip will increase. Shortly, the depth will become uniform over the trough, the new depth being such as will give the same volume of flow. The velocity over the smooth bottom will be unchanged, and the velocity over the rough strip will be that suited to its coefficient of friction and the slope of the trough.

FLOW IN THE OPEN.

Consider a long vertical plane, of considerable width but no thickness, partly immersed in water flowing past the plane with a velocity V_0 where not affected by the friction of the plane. The conditions affecting the flow are composite. If the velocity is great, the retardation adjacent to the plane will be progressive. The width of the wake will increase as the velocity at the plane decreases, and the cross-section of velocities will be of some parabolic form following the laws applicable in the case of the pipe. The total volume of fluid passing will remain constant, but not the volume of individual laminæ, as the height of the water at the plane will not increase in the same proportion as the velocity decreases. The elevation of the surface of the water will extend beyond the outer limit of the wake, and the surface will be only slightly raised at the plane.

If we neglect the effect of eddies, we may consider that the reduction in velocity which has occurred at a given distance from the front of the plane will be greatest adjacent to the plane and decrease as the distance from the plane increases, until the original velocity of flow is reached. The width of this frictional wake will depend upon the reduction of velocity adjacent to the plane, and upon the value of $\tan \alpha$ corresponding to the roughness of the surface of the plane, and the reduced velocity. It will depend also upon the nature of the curve of velocities across the section of the wake, as in the case of the pipe. This curve of velocities at any cross-section can be determined by considering that the loss of head outboard of any section parallel to the plane must be balanced by the friction occurring in the wake at the longitudinal section in front of the cross-section selected.

If the surface of the plane is such that the distance from the cutwater is considerable before a great reduction in velocity occurs, so that the elevation of the surface of the water can be neglected, it seems probable that the curve of velocities across the wake resembles a cubic parabola.

Even if the elevation of the surface is small, for a given reduction in velocity, the total loss of head will be less than if there were no elevation of the surface, and the reduction in velocity will occur at a less distance abaft the cutwater. At low speeds, it is probable that the influence of the rise of the surface will be appreciable, and this fact may account for the observed irregularity in the resistance of models when towed at the lower range of speeds.

The increase in "position" head of a lamina of water for each foot of depth for each per cent loss of velocity is shown in Fig. 7, Plate 60. The loss of velocity head for each per cent loss of velocity for an initial velocity of 10 foot-seconds is shown on the same figure. Corresponding curves for the whole width of the wake are shown in Fig. 8, Plate 60, based on the assumption that the velocity curve across the wake is a cubic parabola. As the elevation of the surface cannot be maintained in the open, the curves giving the increase in position head are of interest only as showing the initial relation between the two effects.

If we neglect the effect of eddies and of elevation of surface, and if F, the coefficient of liquid friction of water, is considered known, as well as f, the coefficient of friction of the surface of the plane in water, the resistance may be calculated by determining the length of the surface corresponding to a definite change in velocity due to the friction. For instance, from equation (2) we determine the values of tan α corresponding to velocity V_0 and to velocity 90 per cent of V_0, the latter value being 81 per cent of the former. Considering the velocities between the surface of the plane and the unaffected water to be represented by the ordinates of a cubic parabola, the breadth b of the water affected by friction at the distance l from the cutwater, at which the velocity of rubbing is $.90V_0$, is found by construction as—

$$b = \frac{3 \times (V_0 - .90\,V_0)}{\tan \alpha_{.90}} = \frac{.3\,V_0}{.81 \tan \alpha_{1.00}} \tag{3}$$

The corresponding value of $H - h$, the velocity head remaining in the cross-section of the wake at this point, can be calculated, and is found to be $.951\frac{V_0^2}{2g}$. The loss of head due to friction, therefore, in this length l, is $.049\frac{V_0^2}{2g}$. This loss of head is also—

$$h = \frac{f}{w \,.\, b}\int_L V^2 \,.\, dl = \frac{F}{w \,.\, b}\int_L^0 \tan \alpha \,.\, dl \tag{4}$$

If the intervals in the velocity are taken sufficiently close, this value of h may be taken as that due to the value of tan α corresponding to a velocity slightly less than the mean velocity. For the particular instance, we have—

$$L = \frac{w \,.\, b \,.\, h}{F \,.\, \tan \alpha_{.93}} \tag{5}$$

The resistance R is obtained when the length is known:—

$$R = f\int_L^0 V^2 . dl = F . \tan \alpha_{.93} . L = w . b . h \tag{6}$$

Table 1, Plate 56, giving the functions for determining frictional resistance, was obtained by assuming a value of 1.00 for tan α at velocity $V_0 = 1.00$. The values of l, the length between the intervals of velocity; of L, the total distance aft of the cutwater; of b, the breadth of the wake; of r_F, the resistance due to friction corresponding to the interval in length l; and of R, the resistance corresponding to the total length L, can be found from these functions as follows:—

$$h = \text{function } h \times \frac{V_0^2}{2g} \tag{7}$$

$$b = \text{function } b \times \frac{V_0}{\tan \alpha} \tag{8}$$

$$h \times b = \text{function } h \times \text{function } b \times \frac{V_0^3}{2g . \tan \alpha} \tag{9}$$

$$\text{mean} \tan \alpha = \text{function mean} \tan \alpha \times \tan \alpha \tag{10}$$

$$\frac{h \times b}{\text{mean} \tan \alpha} = \frac{\text{function } h \times b}{\text{function mean} \tan \alpha} \times \frac{V_0^3}{2g . \tan^2\alpha} = \text{function } l \times \frac{V_0^3}{2g . \tan^2\alpha} \tag{11}$$

$$l = \frac{w}{F} \cdot \frac{h \times b}{\text{mean} \tan \alpha} = \text{function } l \times \frac{w V_0^3}{2g . F . \tan^2\alpha} \tag{12}$$

$$L = \text{function } L \times \frac{w V_0^3}{2g . F . \tan^2\alpha} \tag{13}$$

$$r_F = \text{function } l \times \text{function mean} \tan \alpha \times \frac{w V_0^3}{2g . \tan \alpha}$$

$$= \text{function } (h \times b) \times \frac{w V_0^3}{2g . \tan \alpha} \tag{14}$$

$$R = \Sigma r_F \tag{15}$$

For the same roughness of surface, remembering that tan α varies as V_0^2, we find from the preceding equations that—

b varies inversely as V_0.
h varies as V_0^2.
L varies inversely as V_0.
R varies as V_0.

It will be seen that for constant value of the product of the velocity by the length of surface, the resistance varies as the velocity.

The curves of resistance for varying lengths are plotted in Fig. 9, Plate 61, for speeds of 800, 600, 400, 300, 200 and 100 feet per minute, as determined from the above considerations, assuming $F = .03538$ and $\tan \alpha = 10.000$ for speed of 600 feet per minute. Curves of resistance for the same speeds as given by Mr. W. Froude for shellacked surface are shown in Fig. 10, Plate 61.

The theory as above exemplified does not fit in with the numerous experiments in which the resistance has been shown to vary as the square of the velocity. It seems to be only for rough surfaces, however, that the resistance appears to vary as the square of the velocity, and in such cases the effect of the elevation of the surface of the water would appear to be too important to be neglected. For the same length of surface, the resistance at low speeds would be less than when this effect is negligible, while its influence diminishes as the speed increases. This may account for the higher exponent for rough surfaces.

The theory may be summarized as follows:—

1. Frictional resistance per unit of surface varies as the square of the equivalent rubbing velocity determined by considering the flow to be laminar.

2. Friction between adjacent laminæ of the fluid varies as the rate of change of velocity occurring at their boundary.

3. In the case of a fixed body and a moving fluid, the frictional resistance experienced up to a given distance abaft the cutwater must be balanced by the loss of head in the wake at the same distance abaft the cutwater.

4. The width of the wake at a given distance abaft the cutwater and the reduction of velocity in the wake at various distances from the fixed body may be determined by the consideration that the loss of head outboard of any lamina is equal to the frictional resistance experienced by the lamina before reaching the given distance from the cutwater.

5. The determination of the loss of head in the wake is complicated by the condition that the volume of the fluid passing the fixed body is not altered, although the velocity in the wake is decreased. The consequent elevation of the surface of the fluid becomes of considerable importance when the velocity is relatively small or the reduction in velocity occurs quickly on account of roughness of surface.

6. The energy and action of the eddies may be assumed to be such that the loss of head may be determined as though the flow were entirely laminar.

In conclusion, it may be noted that laminar flow in the open seems hardly in accordance with all the facts as observed, since the friction of wind on water produces waves.

DISCUSSION.

THE PRESIDENT:—This paper on "The Theory of Fluid Friction" is now open for discussion. Is there any member who desires to discuss the paper?

MR. W. L. R. EMMET, *Member of Council*:—The subject of this paper is not exactly in my line, but I happen to have had an experience in connection with it that I think might be interesting to some members of this body.

About twenty years ago Mr. H. W. Buck and I got the idea of building a toboggan boat, because we saw that in Schenectady we had a peculiarly good opportunity for trying one. We have about 2½ miles of absolutely straight track beside the Erie Canal, and we used it for experimenting with electric cars.

We felt interested, and at our own expense built a boat about 25 feet long. We rigged up a powerful electric car, with a tow-line, a speed indicator on the action of the car, and a recording dynamometer on the tow-line of the boat. We loaded the boat to various loads and towed her at speeds from 1 to 31 miles an hour, and took records of the tow-line pull and speed.

As I anticipated, the boat ceased to make waves when she reached a moderate speed, something like 15 miles an hour, and simply slid on the surface of the water without producing a ripple. That indicated that the one thing which was resisting the boat was friction. The records taken seemed to indicate that the friction at these high speeds is quite different from that which the formulae given in books on naval architecture indicate.

I attributed this to the fact that a great deal of air passed under the bottom of the boat, and I have heard among others the suggestion that air passing between water and the surface of the boat might make a large difference in the skin friction. I also know that that has been experimented with at low speeds and that the experiments have shown practically no apparent difference.

From the curves which we took on our boat, I am rather inclined to think that at very high speeds, such as those which are considered in ships nowadays, the introduction of air might make a large difference. Of course the nature of the losses from friction must be due to the fact that a certain amount of water has imparted to it the motion of the vessel, and after receiving that motion, that it must lose it and convert it into heat. You can easily imagine in a large amount of air passing over a surface there might be such a foam produced that the actual supply of water to the surface would be insufficient, and it would simply shear the foam, which might involve less friction than the actual contact with pure water.

If we consider very high-speed vessels, it is easy to calculate that a very large amount of air could be put under them with a comparatively small expenditure of power, and, furthermore, that if the air were released under the vessel, the vessel would be bound to overrun it; it could not rise to the surface quick enough to avoid being overrun.

I just mention this subject briefly, thinking some one interested might want to get such data, in which case they could use the same facilities, which are still there.

MR. F. B. SMITH, *Member*:—My comments are intended more to elaborate on the remarks of Mr. Emmet than as a discussion of the paper. I think I brought up that subject myself several years ago, about the air under the boats having a great effect on their speed.

I refer particularly to light boats. Our lake steamers, of course, as most of you know, are flat-bottomed, with a spoon bow, and when they are running light their bow is entirely out of water. They plane up to such an extent that sometimes, when a boat is running with very little water ballast in her, as she is standing the propeller will be out of water as much as 18 inches. When she is running she planes up so much forward that her propeller wheel is completely buried, and great volumes of air—great pockets—come under the bow and go backward sometimes 250 to 300 feet, some of the pockets going back farther than that.

I was under the impression at the time that I spoke of that that there would be less friction with these air pockets under the bottom of the boat. But since that time I have been considering the subject, and I would like to have some of the scientific men here (as I am a practical man, not a scientific man) who have considered the subject, of these bodies of air coming under the bottom and helping to plane the boat up and lifting her still more out of the water so that there is less surface friction than if the air did not come under the bottom, state why it is we get such wonderful speeds out of these boats through this planing. When they are standing still the turn of the fore foot will be even with the water, and when they are running sometimes 10 feet of the keel will stand out of water and the stern go down deeper in proportion. For that reason the engineers will pump them out until the tops of the blades are 18 inches out of water in a standing position, and when they get going the bow goes up and the stern down. The consequence is they get the full force of the water on the wheel and the boat is lifted bodily up, like an aquaplane to a certain extent.

Mr. Charles H. Lees (Communicated) :—I thank you for the copy of Mr. Gatewood's paper on "A Theory of Fluid Friction."

The problem provided by the friction of a fluid in turbulent motion is a very important and a very difficult one, and no one is more anxious to welcome a satisfactory solution than the naval architect. I am afraid Mr. Gatewood has not succeeded in finding the solution. His theory appears to me to be a revival of the theory published in the Memoires of the Academie des Sciences in 1877, and known to be unsatisfactory even for the simple case of turbulent flow through a pipe.

It is only necessary to quote Mr. Gatewood's result on page 80 of his paper, that the resistance R varies as the velocity V_0, to show how far his theory is from explaining the skin friction of ships, which is known to vary as the 1.8th power of the speed.

Mr. Gatewood (Communicated) :—In connection with the communication of Mr. Lees I would merely state that he seems to have misunderstood the reference in the paper that the resistance varies directly as the speed. This statement in the paper is accompanied by the further statement that the length over which the resistance is measured varies inversely as the speed. The result of these two statements is that the resistance for a given length varies as some power of the speed less than the square, but this power of the speed may not be constant. This is shown by an examination of Fig. 9, Plate 61.

The President :—Is there any further discussion on this subject? As there is no further discussion, we will give Mr. Gatewood a vote of thanks of the Society for his interesting paper, and proceed to the next paper, No. 10, which is entitled "Notes from the Model Basin," by Naval Constructor Wm. McEntee. In the absence of Naval Constructor McEntee, this paper will be presented by Professor Sadler.

Professor H. C. Sadler, *Member of Council*:—I think this is a very valuable paper, especially in connection with the results of the propeller experiments. We have all had experience with somewhat similar designs of propellers giving very different results, and if we examine the curves given here for a rough surface versus a smooth surface, probably that will explain some of the difficulties that some of us have had in showing why two propellers of apparently similar design have given very different results. If there is a difference of from 36 to 72 per cent in the efficiency by roughening the surfaces of the propeller, I think that will explain in a good many cases the differences that are obtained in practice with similar propellers, even though the limits are not as high in the actual propeller as in the model.

In Fig. 7, Plate 60, the effect of even using a smooth surface as against a moderately smooth surface is also brought out in a very good way. There is quite a considerable difference in efficiency, thrust and torque in the smooth surface propeller as against the moderately rough surface propeller.

With regard to the question of wind resistances, the installation of the wind channel at Washington, I am sure, will prove a very valuable adjunct to the model tank. In vessels particularly of this collier type, it is very difficult to estimate what is the effect of wind resistance. There are so many uprights, braces, stays and riggings that we cannot tell, without actual experiment, what the horse-power would be in order to overcome the wind resistance. I can only hope that in the future further experiments will be made on this subject of wind resistance of models.

NOTES FROM THE MODEL BASIN.

By Naval Constructor William McEntee, U. S. Navy, Member.

[Read at the twenty-fourth general meeting of the Society of Naval Architects and Marine Engineers, held in New York, November 16 and 17, 1916.]

During the last year at the United States Experimental Model Basin the press of routine work has been such as to prevent any original investigations which would require the use of the basin for any great time. There has been opportunity, however, to continue experiments relating to the part played by the frictional resistance of water in the resistance and propulsion of ships.

The results of the tests reported in my paper, "Variation in Frictional Resistance of Ships with Condition of Wetted Surface," read before the Society last year, indicated the importance of the condition of wetted surface as affecting the resistance of a ship. As a natural extension of this investigation, an attempt has been made to ascertain the corresponding effect of surface condition on the efficiency of propellers.

The results as given in the present paper indicate that this is a matter of equal importance as affecting the economical operation of ships.

Propellers used for naval work have customarily, especially on high-speed vessels, been carefully finished by machining the rear surface of the blades to a true helicoidal surface and finishing by hand the leading face so as to make the entire surface smooth and polished. In doing this, however, it seems that the object was as much to get blades which would have uniformity of pitch and balance as to get a smooth frictional surface. For merchant vessels propellers are commonly made with blades of cast iron or cast steel, and no finish is given except trimming off the rough places with a chisel or rough file.

To ascertain what may be expected from the difference in naval and merchant practice, four 16-inch propellers, made as closely as possible to the dimensions shown in Fig. 1, Plate 62, were tested at a uniform speed of 5 knots.

Two propellers were of bronze, one of cast iron, and one of cast steel, and all were models of a propeller which has given excellent results in actual service on a battleship. The appearance of these models is shown in Figs. 2 to 5, Plates 63 to 66.

Propeller No. 285 was already on hand. It was machined to a true helicoidal surface on the rear face of the blades, and finished by hand to a true surface of convex section on the leading face. The accuracy of finish was the same as that of the series of propeller models heretofore tested from time to time at the model basin. The three cast propellers were supplied through the courtesy of Mr. William Gatewood, naval architect of the Newport News Shipbuilding and Dry Dock Company. They were made from a separate pattern and were cast as nearly as possible to the finished dimensions of model No. 285.

The results of the tests are shown in Fig. 7, Plate 68, from which it will be seen

that the effect of the rough surface of the models as cast is to reduce the maximum efficiency as compared with the smooth model from about 72 per cent to about 63 per cent.

When a vessel lies for even short periods in waters where fouling occurs rapidly there is frequently a considerable accumulation of barnacles and other sea growth on the propeller. In order to investigate the effect to be expected from the worst probable condition of propeller surface, propeller No. 285—that is, the bronze propeller with smooth finish—was varnished, and while the varnish was still soft there was applied a covering of granulated cork such as is ordinarily used in ship work for cork paint. The appearance of the smooth-finished model and of the same model covered with granulated cork is shown in Figs. 5 and 6, Plates 66 and 67. The results of the test are shown in Fig. 8, Plate 69.

From this it will be seen that the effect of the roughening of the surface is to reduce the maximum efficiency from about 72 per cent to about 36 per cent. If compared on the basis of the same thrust, the prejudicial effect of the rough surface will be even more pronounced.

AIR RESISTANCE OF A SHIP'S MODEL.

During the trials of the U. S. S. Neptune it was found that a considerable variation of power was required to maintain a given speed, depending on the direction and force of the wind. As the Neptune is a collier with a large number of coaling booms for rapid handling of coal, the top hamper presents a large area for the wind to act on, so an investigation of the air resistance seemed desirable.

As there was available an "Exhibition Model" of the ship to a scale of ¼ inch to the foot, on which all top hamper, including rigging and deck obstructions, were carefully fitted to scale, the resistance of the model was measured in the wind tunnel at the model basin.

On Figs. 9 and 10, Plates 70 and 71, is shown the appearance of the model as suspended in the tunnel, and on Fig. 11, Plate 72, the results of the test.

From model experiments in water it is estimated that the vessel, which is 542 feet in length over all by 65 feet beam, with a displacement of 19,340 tons at a draught of 27.5 feet, would require about 3,850 effective horse-power to attain a speed of 14 knots.

From the curves on Fig. 11, Plate 72, it will be seen that with a wind directly ahead with an absolute velocity of 30 miles per hour and velocity relative to the ship of about 46 miles, the additional effective horse-power to overcome wind resistance would be about 770, or 20 per cent of the power to overcome the water resistance alone. This comparison leaves out of consideration any increase in water resistance due to waves. If the power developed by the engines were not increased, this additional resistance of the wind would cause a reduction in speed of about 1.9 knots.

In a general way the results of the test in the wind tunnel confirm the results obtained on trials of the vessel. No exact comparison, however, is possible, because of lack of accurate observation of the velocity of the wind at the time of the trials.

DISCUSSION.

THE PRESIDENT:—This paper which has just been presented entitled "Notes from the Model Basin," is now open for discussion. Is there any member who wishes to discuss it?

PROFESSOR C. H. PEABODY, *Member of Council:*—I wish to point out one item, not in the way of criticism, because I think Naval Constructor McEntee is perfectly conversant with this matter, namely, that these experiments show in a marked manner the disadvantage of roughness, but clearly do not allow us to estimate the effect of roughness, as it does not follow the law of mechanical similitude.

This work is extremely interesting, relatively, but in my opinion we do not need to look for such a great loss of efficiency as these curves would indicate. They do show the great advantage of having propellers properly finished. However, there is another reason why propellers should be finished, and that is, cast propellers seldom have their intended pitch, if, in fact, they have any pitch at all.

MR. WILLIAM GATEWOOD, *Member:*—Mr. McEntee states that if compared on the basis of the same thrust the prejudicial effect of the rough surface of the propellers would be even more pronounced. I think it would be very interesting if Mr. McEntee would prepare a curve on the basis of thrust and show that up. On the face of his curves, they appear to indicate that a smooth propeller has a lower efficiency at small slips than a rough propeller; but when you plot on the basis of thrust you will find that the smooth propeller has increased efficiency throughout the whole range of the experiments.

I think it would also be well if Constructor McEntee will give us a little information in connection with the air resistance on the ship's model, on what basis of comparison he arrived at the probable value of the horse-power required to overcome the wind resistance for the full-sized vessel.

NAVAL CONSTRUCTOR MCENTEE (Communicated):—The point made by Professor Peabody that the results of these experiments cannot be extended directly to the full-sized propeller because of lack of the same relative roughness on the cast model propeller and the cast full-sized propeller, is well taken. In order that the comparison could be made direct, it would probably be necessary that the linear dimensions of projections forming rough places on the full-sized propeller should be in proportion to the size of the propeller. This with a casting, of course, is not at all likely, because using sand of the same coarseness in moulding, the full-sized propeller would be relatively less rough than the model propeller. The variation from the true pitch likely to be found in a cast propeller would probably affect both the model and full-sized propeller in about the same degree.

With regard to the possible roughness of a propeller, I think that an examination of the photograph of model No. 285 (Fig. 5, Plate 66), cork painted, will give an idea of the scale of the roughness, and that it could easily represent an actual full-sized propeller which, by fouling, would have much the same appearance if photographed and reduced to the same size as that given in the paper. In other words, I think that on an actual propeller it would be possible, by a heavy accumulation of sea growth, to reduce the efficiency by one-half.

Referring to Mr. Gatewood's discussion, it will be noted that the curves of efficiency for the cast propellers show a higher efficiency at very low or negative slips where the amount of power and thrust developed are very small. As this is a point at which a properly de-

signed propeller would never work, it does not seem necessary to replot the curves on the basis of thrust instead of slip. If it were done, the efficiency for the cast propeller would at all parts of the curve lie below that for the smooth propeller.

In testing the model of the Neptune in the wind tunnel, the model was suspended as shown in the photographs accompanying the paper. With the air in the wind tunnel flowing at varying measured velocities, the actual total resistance of the model was measured. From this measured resistance was deducted the resistance of the suspension gear and also the estimated frictional resistance of the wetted surface, this latter being estimated in exactly the same manner as the frictional resistance of water for a ship, the only difference being the use of a smaller coefficient for air than for water. Having obtained the net air resistance of the model in pounds, it was extended to the ship by assuming it to vary as the square of the linear dimension and as the square of the speed. This resistance multiplied by the speed of advance of the ship in the water gives the additional horse-power required to overcome the air resistance.

It was thought that it might be possible to compute the air resistance of the model by use of a formula:—

$$R=KSV^2$$

in which R is resistance in pounds, K the resistance in pounds of a square foot of surface set at right angles to the flow of air, S the total projected area of the ship above the water line, and V the speed. The constant K for air is about .0033 pound per square foot. It was found, owing to interference caused by one projection masking another, that no apparently very consistent ratio between the resistance so computed and that actually obtained could be found.

The President:—Does any one else wish to discuss the paper? If not, we will tender to the writer of the paper, Naval Constructor McEntee, the thanks of the Society for this interesting paper, to which I am sure he is entitled.

We have now reached the end of the program of papers for to-day, and the address by Mr. W. H. Ewertz on the submarine will not take place until half past three o'clock.

We will now take a recess until 3.30 o'clock.

Thursday, 3.30 P.M.

The President:—I have the pleasure of announcing that Mr. E. H. Ewertz is ready to make his address and show his lantern slides on the submarine.

Mr. Ewertz then proceeded to deliver the address on submarines.

The President:—I am quite sure you will all agree with me that Mr. Ewartz is entitled to our very sincere thanks for the illustrated lecture on submarines which he has given us. All in favor of rendering a vote of thanks to Mr. Ewertz say "Aye"; contrary-minded, "No." It is carried.

The program for the day is over, and you will be kind enough to come here to-morrow at 10 o'clock, and we will start with the second day's proceedings.

The meeting then adjourned.

THIRD SESSION.

FRIDAY MORNING, NOVEMBER 17, 1916.

President Taylor called the meeting to order at 10.30 o'clock.

THE PRESIDENT:—We will take up first this morning paper No. 9, entitled, "Military and Technical Considerations of Battleship Design," by Naval Constructor R. D. Gatewood, Member.

Naval Constructor Gatewood presented the paper.

MILITARY AND TECHNICAL CONSIDERATIONS OF BATTLESHIP DESIGN.

By Naval Constructor R. D. Gatewood, U. S. Navy, Member.

[Read at the twenty-fourth general meeting of the Society of Naval Architects and Marine Engineers, held in New York, November 16 and 17, 1916.]

The whole history of warship design has been a long series of steps toward increased displacement, and, except for our own battleships Idaho and Mississippi and one or two classic examples abroad, there have been thus far practically no backward steps. By studying, even casually, the progress of the science of building warships, one is at once struck with the fact that the improvements effected in the various types have been made possible largely through this increase in displacement. The true influence that may be ascribed to increased size has been greatly confused because of many concurrent changes in other features of ship design and operation; stronger materials have made it possible to build lighter hulls, to use higher steam pressures and to install more powerful guns; new types of propulsive machinery have resulted in increased speed or greater fuel economy; improved processes of manufacture have decreased cost of construction. Always, however, an inevitable law of growth has asserted itself and each successive vessel of every class has been larger than its predecessors.

In the case of battleships the tendency toward greater displacement would have been even greater were it not for two very important and practical objections:—

1. The extreme reluctancy on the part of governments to spend such large and always increasing sums on single units of power.

2. The great difficulties in providing docking and harbor accommodations for vessels of the giant size demanded by those responsible for using these vessels in battle.

Means have been devised, as, doubtless, means will continue to be devised, to overcome these objections, but is there not a limit to this increase in dimensions? If so, what are the governing considerations that are likely to determine this limit?

The problem of the United States, or indeed of any other country, is not so much whether its needs may be served best by large or small battleships, because, after all, the terms "large" and "small" are vague and relative in the extreme, but rather, what are the minimum dimensions of the ship that will best meet our needs?

These dimensions are influenced and determined by four factors:—

1. Our national policies.
2. Considerations of strategy and tactics.
3. Technical limitations.
4. Cost.

Let us cast aside all preconceived ideas as to size and analyze with an open mind the influences of each of these governing factors on the military and technical characteristics of battleship design. From the facts developed by this analysis, let us then try to arrive at our minimum dimensions, bearing in mind always that the design thus determined merely gives "expression to the technical ideas and intentions of the epoch."* Also, that one should "hesitate to go on record for all time, as the rapid changes in conditions, improvements in material, and increase in knowledge make it desirable to reserve the right to change one's mind in order to keep up with, or go ahead of, the procession."†

POLICY AND SHIP DESIGN.

Fundamental questions affecting a state's welfare, comfort, and sometimes its very existence—questions that are the living embodiment of the will of its people —are called its policies. We have gradually accumulated a set of policies giving us contact with many other states along virtual frontiers approached in extent by those of England alone. By virtue of certain geographical, racial and economical conditions over which we have no appreciable control, these policies now conflict, and will continue to conflict, with the vital interests of various other world states. In the analysis of the relative seriousness of these conflicts, the statesman should reason out which state is likely to be our most probable opponent, and then should adopt a definite naval building program against that state. Our Congress has never done this, and yet the development of our fleet, if it is to uphold these policies, must be absolutely linked up with them.

Lacking a well-defined foreign policy, it was not until some time after the advent of the new steel navy that the United States made any material progress in the design of new types. At first, due to this lack of a definite policy to direct our efforts, we took one or two backward steps. As a natural consequence of "political drifting," we proceeded to copy foreign designs—designs embodying definite policies of foreign nations. Our needs could hardly have been expected to be met by following the policies of these nations, and there resulted several misfits. More are bound to result unless we are guided in the design of our battleships by a definite and sound foreign policy, and in the future, as in the past, we are certain to develop units and even whole classes that may be excellent specimens of naval architecture but that are entirely unsuited to the needs of the country.

If this policy indicates that our most probable opponents are to be black on the one side and yellow on the other, then our battleships must be so armed and protected as to be able to meet the battle fleets of black or yellow on slightly more than equal terms. Therefore they should possess armor-piercing guns of greater power and caliber, and since, actually, our probable enemies are separated from us by the

*Admiral Sir Cyprian Bridge. Paper before Jubilee Meeting, Naval Architects and Marine Engineers.
†Ex-Naval Constructor R. H. Robinson. Paper before Naval War College, August, 1911.

width of an ocean, they must possess such speed, endurance and radius of action as to effectively wage war in any waters of the world.

Thus do our national policies exercise a very legitimate control on battleship design.

STRATEGY, TACTICS AND DESIGN.

Besides recommending a building program providing for the number of battleships to be constructed each year, the General Board defines the military characteristics of our battleships, namely, the size and arrangement of battery, extent of protection, speed, and radius of action, indicating the relative importance of the various main features. This definition of military characteristics is reached after having compared our national policies with those of other states as to the most probable sources of conflict, and after having considered the numbers and types of battleships of our most probable opponents. In arriving at these decisions the most valuable aids are the data derived from the analysis of the strategical problems and tactical studies of the war-game worked out either by the game-board of the War College or by the movements of actual ships of the fleet simulating a naval engagement. These studies have shown conclusively that—

Under modern conditions the gun is the principal weapon of the battleship, and concentration of superior gun fire at the decisive point at the critical time is always the key to victory.

With equal units, naval gun power can be assumed to vary as the square of the number of guns that can be brought to bear.*

The mere possession of a greater number of units is useless unless this superiority in number can be employed in a concentrated way at the proper time.

There should be no reserves in a naval battle.

"The entire force should be brought into action as nearly simultaneously as possible, so distributed as to afford mutual support, and if practicable in such manner as to isolate a part of the enemy from the battle while the remainder is being defeated."

Reasoning from the above premises, it is obvious that concentration of armament constitutes an overwhelming advantage and is in fact an absolute necessity. The great length of battle line and the great difficulties in maneuvering due to the number of units in the present day fleet imperatively demand that, from the point of view of gun fire, as many main battery guns as possible should be concentrated on as few units as possible.

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*"Suppose F_1, F_2 opposed to A, all three being identical ships, each capable of firing one round a minute, and assumed to be put out of action by four rounds.

A would be destroyed by $F_1 + F_2$ in two minutes. $F_1 + F_2$ would be destroyed by A in eight minutes. Therefore $\frac{F_1 + F_2}{A} = 4$. That is, the fighting value of two vessels fighting one is four times as great as that of one vessel fighting two. Similarly, three vessels fighting two would stand to them, in point of fighting value, in the ratio of $\frac{9}{4}$." See Baudry, "The Naval Battle," p. 99.

ARMAMENT.

As long as the gun continues to be the major weapon, the main function of the battleship will be to provide the best possible platform on which to bring it into action. Our guns should possess greater power and destructive effect than those of our most probable enemy, and, since they are now no larger, we must allow for even greater calibers than we have heretofore used. While it is true that in penetrative effect the 14-inch gun at probable battle ranges can pierce any armor that it is practicable to mount in a ship, still, if we accept the principle of maximum destructive effect, we are led almost inevitably to a 16-inch caliber. Such a gun is well within the limits of the present state of the ordnance art, and possesses 30 per cent more destructive effect than the present 14-inch gun of our most probable enemies. The rapidity of fire of the larger gun can be made sensibly equal to that of the smaller, and the heavier weight of projectile will allow us to adopt a relatively low muzzle velocity by means of which both erosion and dispersion will be diminished. Such a gun possesses a materially greater range, and the priority of gun fire thus gained constitutes a material advantage.* It also possesses a greater probability of hitting at long range, and one of the most significant lessons of the European war has been that engagements have been fought and decided at 16,000 yards—a range nearly 3 miles greater than our past estimate of probable battle range.

There is a further reason why we, of all nations, should adopt the larger caliber. Such a gun materially increases displacement and cost. When the present war is over we shall be the richest of nations, and therefore best able to afford the outlay incident to the adoption of the larger gun. Politically, therefore, this may be highly advisable, because of the depressing financial effect on possible enemies similar to that occasioned by the construction of the Dreadnought class by England.

Disposition and Number of Battery.—Bearing in mind the value of concentration of armament and having decided the caliber of the main battery, we come to the best arrangement of the guns.

This is largely a function of the battle formation, and until such time as this shall seem to be logically other than line or column of divisions, or simple column, our centerline vertical-echelon disposition seems best. The question of just how many guns can be advantageously mounted is hardly subject to abstract determination, but it must be quite plain that there is a point at which, after considering the other elements of a design, more guns would only result in a positive loss of efficiency. From a purely constructional point of view, this point has been reached with the four-turret centerline mounting. So overwhelming, however, are the arguments in favor of maximum possible concentration, and so great a length must be provided to obtain the desired speed, that it will probably be best to add one more centerline turret. This is particularly necessary if the 16-inch caliber be adopted, be-

*See Baudry, "The Naval Battle," p. 116.

cause the problems of mounting such guns in triple-gun turrets are not yet solved and in no other way can the demands of concentration of armament be satisfied.*

Speed.—For both strategical and tactical reasons high speed is extremely desirable. If we accept the principle that an active offense is the best defense, speed is essential both for bringing the enemy to action and for maintaining the most suitable range during action. Moreover, speed, when employed in skillful maneuver, assists us to gain that relative numerical superiority which is so essential for concentration. Later on it is proposed to recur to this question of speed in considering the length of battleships, and when the excessive cost of even 2 knots greater speed than that of the enemy is appreciated, it is altogether probable that we should rely on fast battle-cruisers to gain the above advantages rather than attempt to attain too great superiority of speed with the battleships.

No other single feature of a ship has so large an influence on displacement, and every fraction of a knot sacrificed will allow the displacement to be reduced many hundreds of tons. Great ships of this type will always cruise in squadron, and the speed of the squadron will be the speed of the slowest unit. This speed is a function of so many variables—condition of bottom, quality of coal, skill of personnel, condition of machinery, danger of machinery troubles at maximum speeds —and the cost incident to any material increase is so unreasonably great that it would seem wiser to adopt comparatively moderate speed.

Armor.—There will always be a difference of opinion as to the relative importance of guns, speed and armor, but in no one of these three military characteristics is there such a wide divergence of views as in the case of armor. One authority advocates "external protection," completely excluding the shell; another advocates "internal protection," limiting to a minimum destructive effect after penetration; one advocates protection to vitals only, another complete protection; one advocates vertical side armor, another horizontal deck armor. All admit, however, that at the present time the gun bids fair to be the permanent victor over armor. It is not feasible to mount armor of such thickness and area as to exclude all shell, yet at least we should provide such protection to buoyancy and stability, and to magazines, firerooms, engine-rooms, and other vital parts as will render them, as far as possible, safe from all but the largest shell at normal impact. This can be done with the least expenditure of weight by means of vertically disposed side armor. To protect against shell fragments and to preserve buoyancy we must have at least one protective deck located above the deepest possible load line.

The minimum reasonable requirement of armor, therefore, aside from the local protection of turrets, barbettes, conning-tower, and base of smoke-pipes afforded by their own armor, is a belt extending high enough above the normal load water-line to protect the stability, buoyancy and vital military features of the ship, and extending low enough to guard against underwater hits due to naval action,

*For further arguments in favor of restricting the number of turrets to four, see Sir William White's paper before the Society of Naval Architects and Marine Engineers, 1910, and Lieutenant Viani's paper in Supplement to *Revista Maritime*, 1908.

rolling of ship, or heel due to damage. Coupled with this there should be at least one protective deck—all to be of the greatest practicable thickness.

Endurance.—Other great nations of the world as well as the United States have long since abandoned the fallacy of building battleships for coast defense, with consequent small radius of action. As previously pointed out, our battleships should be capable of waging successful war in the waters of our most probable enemies. Since these waters are separated from our own by the width of an ocean, the radius of action of our battleships should be sufficient to traverse this distance to and fro at probable fleet speed, with an additional 2,000 miles or so to cover the cruising that may be necessary until contact can be made with the enemy. This would hardly be practicable with a smaller radius of action than 8,000 miles at 12 knots. Fortunately the advent of fuel oil, together with increased efficiency of ship-form and propulsive machinery, renders it possible to meet this claim with comparative ease.

Protection against Torpedo Attack.—The gun seems certain to remain the supreme weapon of offense, but this superiority is challenged more and more by the formidable menace of the torpedo and mine. No battleship has ever been provided with any sure defense against either of these dangers, and the weakest feature of all existing battleships is their lack of adequate protection against underwater attack. Even now the largest unit of any fleet can be put almost, if not quite, "out of action" by a single torpedo, and in the future there is little to prevent the use of much larger explosive charges to offset any increased subdivision or underwater armor that may be provided. It seems probable, therefore, that the chief defense against this form of attack will consist in a somewhat increased speed of battleships and a cordon of high-speed units of the destroyer type. In addition to the protection thus afforded, every possible provision should still be made to minimize the results of successful torpedo attack, and it will therefore be necessary to provide suitable minute watertight subdivisions and even armor—all of which must add materially to displacement.

This comparatively new effectiveness of the submarine and its weapon, the torpedo, must exercise a powerful influence on the size and cost of individual units, and it is not at all improbable that the eventual development of the submarine may result in driving the battleship from the sea. He would indeed be a rash prophet who would venture to predict when this will come to pass, but until then the development of the battleship type must move forward, or else the type must be abandoned altogether.

TECHNICAL LIMITATIONS.

The above are the most essential military characteristics to be incorporated into the design of our battleships, although there are many others of lesser importance that require due consideration, such as secondary battery, torpedo armament, and type of propulsive machinery. After they are decided the problem presented to the naval architect involves such technical characteristics as buoyancy, stability, maneuvering qualities, and strength. On account of the great number of vari-

ables involved it is capable of numerous solutions of more or less merit, but what we are chiefly concerned with at this stage of the subject is to determine the minimum displacement on which we can expect to meet all these claims.

Design.—In the first place the design of a battleship cannot be made according to mathematical formulæ. Many years ago Rear Admiral Fiske said that he "labored for several weeks in a persistent endeavor to arrive at some law by which, for a given size of ship, the best combination of speed, armor and armament could be determined," and that he "failed to find any such law, largely because he did not know the conditions under which the ship would have to fight." But had he known the conditions he would have been no nearer to his law. No such law exists.

The several elements of a design may admit occasionally of scientific treatment by means of exact empirical formulæ—for example, the buoyancy, stability and speed. But a formula or law does not exist for combining the above elements with strength, endurance, protection and armament, and arriving at the best result. This has always been, is now, and in all probability will continue to be, a matter of opinion—or, rather, difference of opinion—and so let us leave it.

Dimensions.—Displacement is determined by the principal dimensions, length, breadth and depth, and by the form of the lines. Each dimension is determined with respect to absolutely different things, and each one must be thought out carefully by itself, never forgetting at the same time certain empirical ratios with respect to each other that have been found to exist in successful ships of similar design.

Draught.—This dimension is influenced chiefly by such practical considerations as the depth of harbors and docking accommodations. Although designed to operate normally from certain bases, it is plain that battleships should not be materially restricted in their actions to certain fixed ports. It is true that any well-devised battleship-building program should be undertaken concurrently with a program for increased depth of harbors and size of docks, but the practical considerations of the great cost thus involved must always exert a strong influence toward moderate draught. Having in view these reasons, it would be well, at least until harbors and docks have been further enlarged, to restrict the normal load draught of our battleships to 30 feet, the deep load draught not to exceed 32 feet.

Beam.—The question of beam to which we now come is determined somewhat with regard to width of docks,* but more with regard to stability, since the position of the metacenter is determined chiefly by the beam, and the metacentric height is the most important consideration affecting the movements of a ship in a seaway. The position of the metacenter varies directly as the square of the beam, so that if we increase beam, we materially increase metacentric height, initial stability, and the stiffness of the ship in a seaway. This stiffness should be ample to prevent a too great heel when turning or when side compartments are flooded, but not so great as to impair the steadiness of the gun platform and render the motion of the ship jerky and unsteady.

*It is limited, for the present, at least, by the 110-foot width of the Panama Canal locks.

Exact formulæ for the influence of beam on speed do not exist, but model experiments seem to bear out the fact that on a given displacement for an increase of beam of, say, 5 per cent, the effective horse-power must be increased by the same percentage if the same speed is desired, and that if length be kept constant the ratio $\frac{B}{D}$ can be varied widely without any very appreciable effect on resistance.

LENGTH.

This dimension is influenced more by the speed than by any other feature of the design. In order to obtain high speed it is absolutely necessary to have length. To give a concrete example of this, assume that we desire 24 knots speed from a 30,000-ton ship. With a 690-foot length the speed could be obtained with about 40,000 horse-power. Keeping beam and draught constant, but shortening the length to 630 feet, there would be needed 50,000 horse-power, and at 570 feet over 80,000 horse-power would be required; whereas, if we desire only 20 knots speed, it can be obtained on a 570-foot length with but little more than 40,000 horse-power. Furthermore, not only will the shorter ship require much more horse-power for a given speed, but it affords less length for the installation of the increased horse-power, so that practically the length must be great enough to enable the necessary machinery to be installed.

On the other hand, by a too great increase in length we reach a point where the frictional resistance due to increased wetted surface is greater than the gain from reduced wave-making resistance, particularly at cruising speeds. Length is not favorable for maneuvering, increasing the resistance to turning. Length necessitates a serious increase in displacement, due to the greater weight of armor and hull for the same protection and same strength.* Greater length means greater target area, and incidentally there are but few dry docks that will accommodate great lengths.

DISPLACEMENT.

Many other features must be given their relative weight, the chief of which are seaworthiness, freeboard, and type of hull fittings, but enough has been said to indicate the principal military and technical considerations influencing and limiting battleship displacement.

Passing over the more or less mechanical end of the calculations involved, it may be stated that, in the present state of the art of the naval architect and marine engineer, it is not possible to adequately fulfil these principal claims on less dimensions than 640 feet for length, 96 feet for beam, and 30 feet for draught, with a consequent displacement of approximately 36,000 tons.

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*If the same percentage of side is to be protected without decreasing the thickness of armor, the weight of side armor will increase directly with the length. The increase in hull weight is due to the greater area of plating, this area increasing approximately as the square root of the length, and also to the greater thickness of plating which it is necessary to use in order to provide adequate strength to meet the bending moment, which increases roughly as the length.

Thus, although we have restricted the number of turrets to five, and the number of guns to ten, confined our armor to vitals only, used only moderate speed, and employed every technical and engineering means to reduce displacement, we have arrived inevitably at a large ship. Moreover, any ship of less displacement, that is, any "smaller" ship, must be inferior in armament, armor, or speed. Any ship of greater displacement will probably involve a too great expenditure for harbors and docks, and the military gain that could be effected would not be commensurate with the increased cost and other disadvantages incident to great displacement.

COST.

A study of the relative costs of large and small battleships should properly include not only the first or "prime" cost, but the cost of maintenance as well. Above certain displacements it should also include the cost incident to increased harbor and docking facilities, and it has already been shown that this can readily involve such a large expenditure as to materially restrict the dimensions and displacement of capital ships. As regards first cost, perhaps the briefest way to indicate the practical relation in battleship construction existing between cost, displacement and effective gun power is to state that, by increasing the cost one-half and the displacement one-third, it is possible to produce a unit with double the effective gun fire.*

Consequently, if smaller and more numerous units are constructed for the same expenditure, each with an effective gun fire equal to one-half that of our type ship, we may expect to provide only three smaller vessels for every two larger ones; and the effective gun power of the two large ships would be one-third greater than that of the three smaller ships (*i. e.*, in the proportion of 2 to 1.5). Moreover, the cost per annum of manning and maintaining the more numerous fleet will be materially greater. It may be conservatively estimated that this increased cost of maintenance of the three small ships over that of the two larger ones will be less than 5 per cent per annum. Assuming the life of a capital ship to be twenty years, it will cost 100 per cent more to man and maintain the more numerous fleet. It is also to be observed that, although the cost per unit for "large" ships is much greater, the risk of total loss is correspondingly smaller on account of the better subdivision possible to provide on the larger ship, and the greater distance from the skin of the ship at which it is possible to place the boilers and magazines.

FIGHTING VALUE.

Many advantages of the larger units become greater and more accentuated when the fighting value of a fleet of units is considered. This is particularly true when we compare fleets of equal cost. It has been shown that for a given expendi-

*Paper by Chief Constructor F. T. Bowles, U. S. Navy, 1902, The Society of Naval Architects and Marine Engineers; also paper presented by Professor Welch in the spring of 1911, Institute of Naval Architects. See also comparison of contemporary United States designs.

ture of money it is possible to provide one-third more gun power on larger vessels than on smaller vessels each of gun power equivalent to one-half the larger vessels.

If the caliber of guns in the two fleets be assumed equal, then the larger ships possess a one-third greater numerical superiority. This would indicate that the fighting power of the large ships with relation to that of the small ships is in the proportion of $\left(\frac{4}{3}\right)^2 = \frac{16}{9} = 1.77$.*

Furthermore, the destructive value of a fleet is determined not only by the fighting value of its units, but by the method of employing that fighting value. The principal factors in connnection with the method of employing fighting value are (1) maneuver, and (2) fire control. Maneuver enables a fleet to gain that relative numerical superiority of guns required by the principle of concentration. The fewer number of units in the fleet of large ships allows a greater ease of maneuver on account of the handiness of a short line as compared with the clumsiness of a long one, apart from such matters as visibility of signals, etc. If it is argued that the smaller and therefore more numerous fleet possesses a larger power of combination, the answer is that in a naval battle it is not power of combination that we desire but power of concentration.

From the point of view of fire control, the big ship again has a great advantage. Assume three small ships fighting one large one. To anyone who has witnessed long-range target practice and attempted to spot the fall of salvos, it is at once apparent how extremely difficult, if not indeed impossible, it would be to identify the salvos of the three smaller ships as they fall about the large one, whereas the fire-control officer and spotter of the single large ship can concentrate their salvos on either one or two of the smaller ships, identifying unerringly each salvo. The advantage of the small ships due to the "dispersion of target" offered by them would be more than counterbalanced by the great handicap of being unable to identify their salvos.

CONCLUSION.

Since the ultimate purpose in modern war is the disruption and destruction of the organized forces of the enemy, the purpose of our battleship fleet is neither the defense of our coast, the blockade of the enemy's fleet in his ports, the capture of sea-coast forts, nor even the "command of the sea." Its mission—its sole mission—is battle, the complete and relentless destruction of the enemy's battle fleet. To this end it must possess at the outset and maintain by maneuver during battle that relative superiority which is the key of all decisive battles by land or by sea. This can be obtained most certainly, and at a much less cost per gun, by concentration of fighting power in large units.

It has been shown that the fulfilment of the present-day claims on the military and technical characteristics of battleship design imperatively demands a ship of

*See page 93.

large displacement. It has also been shown how each element of a design can be benefited by an increase of displacement. Apart, however, from this gain, the larger ship possesses certain inherent advantages over the smaller one that more than outweigh the disadvantages due to size:—

Greater concentration of armament.

Better protection of buoyancy and stability by comparatively more minute subdivision.

Greater protection by armor, because the thickness of armor need not be increased with displacement, and the same area will protect a greater tonnage.

More economical propulsion.

Greater radius of action.

Greater sustained sea speed under all conditions of weather.

Greater efficiency per gun due to the wide separation of turrets, machinery, magazines, etc., also on account of the greater safeguards it is possible to provide on the large ship with regard to the supply of power, ammunition and every other essential that serves the gun.

Moreover, it is only large displacement which makes it possible to provide that adequate protection against underwater attack which is becoming more and more necessary and which cannot be provided with smaller displacements.

These are the reasons that demonstrate so convincingly the value of the larger ship and that will force us inevitably to build larger and even larger units until such time as the improvement in submarine and aerial offense shall drive the present battleship type from the sea forever.

DISCUSSION.

The President:—Gentlemen, you have heard this paper on "Military and Technical Considerations of Battleship Design." It is now open for discussion.

Professor W. Hovgaard, *Member*:—I am much interested in this paper, especially as Mr. Gatewood is one of my former pupils. The arguments in favor of large ships are stated clearly and well, but the paper does not contain any discussion of contrary arguments. I will say at once that, as matters stand at present, I believe strongly in large battleships, and I am going to present one more argument in their favor. I will show, moreover, that the most weighty and obvious objection to large size, the concentration of risk, does not bear logical investigation.

The Speed-Armament Gauge.—The battles of Dogger Bank and Faulkland Island, as well as several minor actions (Sydney-Emden) in the present war have demonstrated the enormous value of combined superiority in speed and gun power. In fact, a ship possessing the speed gauge and armored with guns of superior power—*i. e.*, guns that are effective at a greater range—can annihilate a weaker enemy at extreme ranges with relatively small risk to itself. This two-fold superiority, for which I venture to propose the name of "Speed-

Armament Gauge," is of an entirely different order from that of either of its component parts, and must be a fundamental principle in future battleship design. A commander whose vessel possesses this advantage will be in perfect control of the situation, since he can accept or refuse battle at will and can fight at ranges where the enemy's fire is ineffective. It is clear that only the wealthiest nations can afford to build a fleet of battleships fulfilling these conditions. The Queen Elizabeth, at the time she was constructed, was a good example of this ideal. Her speed was about four knots higher than that of contemporaneous battleships, and her 15-inch guns were more powerful and had a longer effective range than those of any other navy, but the principle was departed from in the Royal Sovereigns, which were designed for 21 knots only. I do not mean, however, to recommend very fast battleships. The element of speed as a dominating factor ought to be represented in battle-cruisers, but I do believe that those who can afford to do so should give their battleships a somewhat higher speed than that of probable enemies. Even a superiority of one knot combined with somewhat more powerful guns is sufficient to establish the Speed-Armament Gauge, which characterizes the offensive type of battleship, usually the victorious type, at which designers should aim.

Divisibility of the Forces.—At any given time navies are limited by financial considerations to a certain aggregate displacement of their battleship fleet. At the same time, strategic and tactical considerations demand a certain divisibility of the fleet, *i. e.,* a certain number of units, and thus a limit is imposed on the displacement of the individual ship. In many smaller navies this limit is long since reached, but in case of the United States, in spite of the great claims to divisibility, it need hardly be considered as yet.

Size in Relation to the Risks Incurred by Accidents and Losses.—Even if all the technical and military advantages claimed for large ships are admitted, it remains to be shown that the chances of loss and disablement, measured on a percentage basis in a fleet of a given aggregate displacement, does not increase with the size of individual ships. Evidently, the larger the ships and the smaller their number, the more serious is a mishap to each one unit; and it is of the utmost importance to investigate whether this concentration of risk is justified.

Every ship, however large, is exposed to certain dangers of navigation, of which the most important are those due to grounding and collisions, which may result in temporary disablement or total loss. All ships, moreover, are liable in the ordinary course of service, to be put out of commission by breakdowns in machinery and appliances, necessitating shorter or longer visits to ports where repairs can be carried out. In time of war there is to be considered in addition the dangers incidental to attack by artillery, torpedoes and mines, and the increased liability to breakdowns due to the more intense service. Considering first the dangers of navigation and the chances of breakdowns of the *matériel,* the frequency of such mishaps must be directly proportional to the number of units; or, what comes to the same, the percentage absences or losses in a fleet, whether measured in tonnage or in units, must be the same in case of small as in case of large ships. If, in a squadron of eight ships, one ship is liable to be disabled during a certain period of time, it is probable that two out of a squadron of sixteen ships of half the size would be disabled in the same period. The percentage loss will be the same in either case.

It may be argued that larger vessels are more liable to run aground than smaller on account of their greater draught, and that they are more exposed to collisions due to their inferior maneuvering qualities, but these drawbacks are probably more than offset by the fact that a smaller number of larger vessels can be better equipped for navigation both as regards

personnel and *matériel,* and can be more minutely subdivided. The *matériel* can be better safeguarded against accidents and breakdowns. It is concluded that on the whole the risks incident to navigation and ordinary service are not enhanced by going to large displacements.

As regards the risks peculiar to war conditions, the intensity of attack, to which warships are exposed, will be in a broad sense directly proportional to their size, because, again, the number of units is reduced in the same ratio as that in which the displacement is increased. Larger ships, therefore, would be more liable to damage and destruction than smaller, unless the means of protection and defense can be developed and strengthened in the same measure as the intensity of attack is increased, but this, in fact, appears to be quite feasible. The degree of protection that can be obtained by passive means, such as armor, subdivisions, under-water bulkheads of special construction, nets, and other appliances, is fairly proportional to the displacement. The active means of defense, whether carried by the ship herself, such as guns and torpedoes, or extraneous, such as patrolling vessels and aircraft, can be likewise rendered proportionately more effective in a fleet consisting of a smaller number of larger vessels than in a more numerous and more scattered fleet of smaller vessels.

Mine attacks, being of a passive nature, are in this connection analogous to the dangers of navigation, under which large and small vessels are exposed to practically the same risks.

I conclude that the risks of peace and war are no greater for large battleships than for small, and that, hence, the one great objection to large vessels so familiar to all, of "putting too many eggs in one basket," cannot be sustained. This, of course, does not preclude the possibility that battleships, as we know them now, may some day, perhaps sooner than we suspect, be driven from the ocean, as they have already been driven from the smaller seas, but that time is not yet.

Captain A. P. Niblack, *Vice-President:*—I had not intended to say very much about this paper, except in praise of it, not only with regard to the subject-matter, but with reference to the breadth with which it has been treated. It is a splendid paper, and the question is considered in a way that I think the Society ought to get used to.

In a Society of this character, whose members belong to various professions and have various interests, the one element which is excluded from the discussion is the political. For instance, in the design of ships—from the shipbuilding standpoint, of course—it may be, in developing a program of shipbuilding, as an example, that one of the arguments in favor of building ships of a certain type (which was true many years ago) was that certain shipyards could build that type and no others. We have been governed in the United States by a good deal of exigency in our program with regard to shipbuilding.

One argument in favor of the large ship, for instance, might very reasonably be that Congress would only give a certain number of ships, and therefore it would be advisable to get the biggest ships that could be procured. That is one phase of it.

We can argue these questions of design from so many standpoints, I think it is important that we discuss these questions on broad lines, as Mr. Gatewood has done, that is to say, strategically and technically. There has been, in fact, a series of papers presented to the Society on this same general subject and published some years ago. At the meeting in 1895 we had a paper entitled "Tactical Considerations Involved in Warship Design." At the 1899 meeting we had a paper on "Tactical Considerations Involved in Torpedo-Boat Design." At the 1902 meeting we had a paper on "The Tactics of the Gun," and at the meeting in 1907 a paper on "Further Tactical Considerations Involved in Warship Design."

These are papers of which I happen to have been the author, and I was interested in the subject treated from the tactical standpoint. I am glad to welcome a discussion on broader lines, that is, of strategy, and this paper is really so full of meat that when it is condensed in the form Mr. Gatewood has condensed it, I only feel sorry that the condensed notes which he has just read cannot be published also, because I think the points are even more admirably expressed in the condensed notes than in the full paper. The full paper gives the argument, but the condensed statement, made by the author, is a delightful presentation, to my mind, of the whole question of battleship design.

There is one phase of the subject which Captain Hovgaard has touched on, and that is that we have not gone in for speed in our navy. The General Board, which is the board which considers general questions of design, and always largely on broad principles, has passed on the question of extreme speed as being one which we have settled rather adversely and conservatively.

The question of big guns naturally comes into this general subject. However, there is no use trying to shoot farther than you can see, and the question in battle is not so much the question of extremely long range, but a question of how far you can spot the fall of the projectiles. You do not get very far without seeing what you are doing. It is very easy to exaggerate the importance of a 16-inch gun as against a 15-inch gun. Firing at 11 to 12 miles, as they do in the fleet now, where you only see the flag on top of the target and not the target itself—that is, you only see the flag from the gun itself—it is easy to exaggerate the importance of this long-range proposition and also of high speed.

I think the Society gains a great deal at these meetings, where the people are assembled who are interested in getting a big shipbuilding program placed in this country—while you are not so anxious this year as in other years—still on the general proposition I think it is well for the Society to take the broad, big view, and this morning I am particularly trying to emphasize the value of the discussion of these questions on the part of technical people along broader lines.

Along these lines I am much gratified, personally, to see this type of paper appear in the Proceedings of the Society. Mr. Gatewood, as a naval constructor, has served in the fleet, and we are getting somewhere near the ideal in our navy when the seagoing naval constructor and the seagoing line officer with the seagoing engineer officer all arrive at points on the same broad line of the requirements of the country in accordance with its policy, and also along sound strategic lines in accordance with sound tactics. Speed is very much more largely a strategic than a tactical question. That is one of the points I want to commend in Captain Hovgaard's comments.

Professor Hovgaard:—In view of what Captain Niblack has said, I want to qualify what I said about the speed of ships. I did not mean to recommend extreme speed for battleships; on the contrary, I think extreme speed should be relegated to the battle-cruisers. I meant to recommend a somewhat higher speed than the standard speed of battleships at any given time. That can only be done by the most wealthy countries.

As to the range, of course I am aware that 12-inch guns can be fired at almost the longest ranges where it is possible to observe the fall of the projectiles. The point is that at the extreme ranges, where spotting is possible, the heavier guns are more effective than the lighter guns.

Mr. Ernest H. Rigg, *Member:*—Captain Hovgaard's last remarks somewhat anticipate a point that I was going to make. Mr. Gatewood's paper is, as Captain Niblack has

stated, a very interesting and valuable contribution; it is easy to say that, and it sounds very much like a platitude, but at the present time, when big things are happening and the people who are in a position to know of them are not in a position to tell of them, that which we get from our constructors, who are necessarily guarded in their language, is of extreme value in indicating the lines of present-day thought and development.

Captain Hovgaard mentioned the speed-armament gauge, and he then went on to the Queen Elizabeth and some of the later ships; there are distinct signs of battle types other than the standard battleship and battle-cruiser.

What I wish to emphasize is this—we have standard battleships of 21 knots, we have fast battleships of the Queen Elizabeth type, and then we have battle-cruisers of higher speeds yet. We are very much interested in battle-cruisers today, and what Captain Hovgaard said about the armament of the battle-cruiser being of the heaviest possible caliber is of distinct value, and it is a statement which should receive very serious consideration at the hands of our naval authorities. The battle-cruiser is of no great value as the fastest wing of the fleet unless it can play the game, to a certain extent, with the battleships. The object of the battle-cruiser, as I take it, is largely to hold and outmaneuver the enemy's battleships, until our own can engage them to the utmost of their capacity. The battle-cruiser should therefore have an armament of the same caliber as contemporary battleships of its own fleet.

Another point Captain Hovgaard reminded me of was in connection with concentration of risk. In my own experience, I have had an example of that which illustrates the point. There was a battleship to be drydocked, and she was not by any means up to the capacity of the dock gate, the clearance being about 4 feet on each bilge. Later there was another battleship to dock in the same place, and the clearance was 1 foot; in fact, 10 inches was the theoretical figure—I cannot guarantee the last 2 inches, as I did not go down to measure it, but it was something less than 1 foot, actual clearance. When we docked the big ship we knew we had to be very careful, so that when we pumped the water down, after docking, there was not a mark on her; the same was not true when we docked the smaller ship. When she was pumped down the bilge keels were considerably damaged on one side.

The point is, when you have something of a higher order you will be more careful than in the case of something of a lesser order; as responsibilities multiply, so, in general, do men size up to them. According to mathematical probabilities, we should have damaged the bilge keels in the big ship, but the damage was done on the little ship; that seems to me to illustrate Captain Hovgaard's point well.

The President:—Is there any further discussion on this interesting paper? If not, I will ask Mr. Gatewood to respond and close the discussion.

Naval Constructor Gatewood:—I want to thank all of the speakers for the nice things they have said about the paper. I will try to do that collectively instead of individually.

This paper was not written as an argument for or against any one particular type of ship, or other types of ship that seemed to be developing. It was written entirely to prove, to the writer more than to anybody else, that if you had a given sum of money to expend you could best expend it on the larger units.

It is not for me to say, it is not my "job" to say, whether you would rather have twenty Wyomings than eleven Pennsylvanias (and you might be able to get them for the

same amount of money). I was very careful not to say in the paper that, if you had money "regardless," you would spend it on Wyomings instead of Pennsylvanias. I do say that if you have a given amount of money only, you had better spend it on Pennsylvanias than on Wyomings.

There is an altogether different argument, and one that I hope some line officer—and the line officer is the only man I know qualified to write on this subject—will some day give us, and that is, considering the money expended, do you want Wyomings, or do you want Pennsylvanias? It is altogether a different subject, a very different argument, and will involve a different paper.

As regards the divisibility of forces, I have nothing further to say, except the general remark that the divisibility of forces will come into the main argument of whether you want a lot of Wyomings or a few Pennsylvanias. It is part of that kind of a paper, and not part of this paper. It is a very important point, and it should form a large part of the argument in favor of whether we want a considerable number of smaller ships or a few large ones. It is most important both from the strategical and tactical side.

As regards concentration of risk, I am very much obliged to Captain Hovgaard for having bolstered up my argument in that respect. I firmly believe, as he so well brought out, that in time of peace you have distinctly less risks with the larger ship; as Mr. Riggs so well brought out, you have a larger unit, you have a much more expensive unit, and you do not even try to get the ship into the smaller harbor. Knowing you cannot go there, you do not attempt it, and with these very big ships you do not try to go into places where you cannot go, and where there should not be occasion to go, even in war time.

As a matter of actual statistics, I believe it can be shown that the large ships are actually absent from their station with the fleet, due to casualties and minor repairs, much less time for a ship than the smaller ship. I mean by that, taking Captain Hovgaard's simile of the eight ships and the sixteen ships, that while the sixteen ships have twice as many risks and run twice as many chances to be out of the fleet, yet, also, the eight ships are constructed along stronger lines, their auxiliaries and accessories are stronger, the scantlings are heavier and better supported, and they do not get out of commission and go wrong as readily as they do in the case of the smaller ships.

As regards the point of better protection which Captain Hovgaard brought out, I was hoping he would reach up my sleeve and get one more argument I saved from the paper, in case some one tried to find fault with the arguments in the summary. It was suggested to me by Naval Constructor Snow and it is that, as regards a given expenditure, it takes less auxiliaries to protect the larger ships, and you do not have to spend so much money in destroyers, hospital ships, colliers, etc. If you have eight Pennsylvanias it does not take more than four destroyers each to look after them. If you have eight Kentuckies it takes the same. If you have a fleet of smaller units, it takes a larger number of auxiliary units, and the expenditure for these can be tacked on to the battleship units, as they must be bought and paid for from the same money the battleships are bought with.

As regards Captain Niblack's criticisms, I want also to acknowledge my indebtedness to his previous papers. I did not put at the end of my paper any set of references to which I had referred. If I had done so, it would be almost as long as the paper itself. The paper required the better part of a whole winter in its preparation, and references, as you will imagine, to a paper attempting as large a scope as that, would be altogether out of order if you attempted to include them in the paper.

As to the point of shooting as far as you can see, it is quite well known to everybody, I think, that a 14-inch gun will penetrate all that is necessary to penetrate. It will penetrate as far as you can see. A 16-inch gun, while it may penetrate a little bit more, has the advantage that its exterior ballistics are usually greatly superior to the 14-inch gun. That is a phase of the situation that very few people take account of, and the two most important features of the exterior ballistics are the destructive effect and the dispersion. Now the dispersion is something which is not spoken of much, but is of immense importance in considering any gunfire installation.

I cannot talk too much about dispersion, and I am not supposed to say too much about it, but I can make it plain by saying that in the case of our 12-inch, 50-caliber gun in shooting as far as you can see, as the Captain so well expressed it, you are straining that gun to get the last atom of strength out of it. The result is when you straddle the target that the salvos have a dispersion of the order of 600 or 800 yards, or even higher, but by going to a 16-inch gun and straddling the target at the same range, you are not straining the gun—you are shooting well within the exterior ballistics of the gun, the straddle is of the order of 200 or 300 yards, and the result is a materially greater number of hits, even if you give the 16-inch gun a much less muzzle velocity, which you would do to take advantage of the larger caliber.

That point is a most important one. You must consider the dispersion of the gun strained to its limit, and you have to strain a 12-inch or even a 14-inch gun to its limit, but you do not have to strain the 16-inch gun. The increased destructive effect is simply expressed by saying that if the two shells hit the same place, the 16-inch shell will do one-third more damage than the 14-inch shell. That should be quite enough for the destructive effect of the 16-inch gun to justify putting it on the ship.

As regards the guarded feature, there is nothing particularly guarded about the paper. It was passed on by the Department. All of the material prepared for the paper was passed on by the Department, and nothing of moment was eliminated, except such as might give definite figures and statistics in support of the statements made in the paper.

The President:—We have certainly listened to a most interesting paper, and quite as interesting a discussion, and on behalf of the Society I tender to Naval Constructor Gatewood sincere thanks for the paper.

We will now take up paper No. 10, entitled, "On the Suitability of Current Designs of Submarines to the Needs of the U. S. Navy," by Captain W. L. Rodgers, U. S. Navy, Associate.

Captain Rodgers presented the paper.

ON THE SUITABILITY OF CURRENT DESIGN OF SUBMARINES TO THE NEEDS OF THE UNITED STATES NAVY.

By Captain W. L. Rodgers, U. S. Navy, Associate.

[Read at the twenty-fourth general meeting of the Society of Naval Architects and Marine Engineers, held in New York, November 16 and 17, 1916.]

In accepting the invitation which the secretary of the Society did me the honor to extend in asking me to contribute a paper on submarines, I do not assume that he had any idea that I would undertake to tell the members of this Society anything in regard to the technical and mechanical features of submarines, with which they are already well acquainted.

But, as president of the Naval War College some years ago, and ever since then, I have given attention to the strategic and tactical fields of work which are open to submarines in naval warfare. A sketch of these fields and a consideration of possible modifications and variations in design of submarines to meet the requirements of warfare seem to me to offer interest to naval architects, and it is along these lines that this paper will be developed.

In thus discussing the subject, it must be borne in mind that while the constructional and engineering possibilities of design are pretty well known and form a stock of knowledge common to designers of all nations, nevertheless the application of this stock of knowledge to the production of concrete designs suitable to the national policy and geographic situation of particular nations will result in types of ships which will differ much according to nationality. This paper will consider some of the controlling factors which should influence American design. In so doing we need not fear the betrayal of any national secret. It is the business of foreign navies through the agency of their general staffs not only to study in advance the requirements of their own forces, but also to examine the situation of other powers which may become hostile to them so as to draw deductions as to the enemy's probable efforts and employment of his forces.

Any enemy in thus considering our types of submarines and their probable employment in war will no doubt start from very much the same premises as we ourselves assume; namely, the well-known constructional possibilities of submarines varying with the progress of invention, the tactical development of the present war in attack by, and attack upon, submarines; and, finally, the national policies and geographic situation of the United States.

Assuming the enemy has equally good reasoning power as ourselves, and granting he knows the ordinary constructional data as to submarines, it is clear that he will necessarily arrive at conclusions much like our own. If we avoid general discussion in the hope of withholding information from foreigners, it is ourselves

who will suffer most, since good-will and a common understanding between the sea-going navy and the industries which support it are essentials to success, and particularly necessary in a democratic nation. In fact, a basis for such a common understanding is provided in the public hearings upon the naval appropriation bills, which give much information as to our policies and views.

The purpose of this paper will, therefore, be first to examine the peculiar military characteristics of submarines in general and compare them with those of other types of combatant ships; second, to consider how these general characteristics will influence or control the employment of submarines in war; and, finally, what particular types of submarines seem best suited to American needs.

Submarines are armed with torpedoes and with guns. Owing to the great percentage of the displacement which is necessarily devoted to the heavy hulls and very heavy machinery installation, the speed of submarines is much less than that practicable for surface craft of the same size. Consequently submarines, unlike torpedo-boats and other fast craft, cannot rely on their speed as a means of safety. For the submarine the chief means of defense is provided by her submersibility and consequent invisibility. Further, the great weight of storage batteries forbids giving submarines more than a small radius of action when submerged. The submarine obtains information only when able to see—at the surface. She can navigate freely and recharge her storage batteries only when running the oil engines at the surface. These are the chief peculiarities which affect the combatant powers of submarines. They affect alike those submarines which are armed with torpedoes and those of that other type, the fruit of the current war, which are designed as mine-layers. Bearing these peculiarities in mind, we may proceed to consider the general principles which these qualities require a captain to observe in the employment of a submarine under his command.

In regard to the torpedo, a pecularity exists which differentiates its use very much from that of the gun. The initial velocity of a projectile from a high-power gun is 3,000 feet per second. The speed of the fastest ship is not over 60 feet per second. As these two velocities are in the ratio of 50 to 1 a ship cannot escape from a projectile fired at her. The greatest velocity of an automobile torpedo seldom exceeds about 40 miles an hour, and this only for moderate ranges. By reducing the speed to 30 miles or less an hour the compressed air in the flask can drive the torpedo farther, but such speeds are of the same order of magnitude as those of the target ship. Consequently, the direction and speed in which the target ship is moving are most important elements in deciding when she is within range. Consider, for instance, a 30-knot torpedo capable of running 10,000 yards. If fired at a ship approaching at the rate of 20 knots there is a chance of hitting if fired at a distance of over 16,600 yards, whereas if the target is withdrawing at 20 knots, the torpedo will exhaust its motive power and stop before overtaking the target if fired from any range above 3,300 yards.

When submerged the submarine itself also is limited both in speed and radius —12 miles at most at 10 or 12 knots, a hundred miles more or less at 5 or 6 knots.

Thus when submerged the submarine's area of action resembles that of the torpedo which it carries as its chief weapon. It cannot chase to advantage when submerged. We cannot give a submarine the highest surface speed because of the heavily built hull and the heavy storage batteries. Such surface speed as we are able to confer on a submarine is inadequate for the tactical requirements of battle. It may enable a submarine to assume a favorable position for submerging ahead of an approaching enemy, but it cannot be great enough to be satisfactory in the tactical approach, as is the case with the torpedo-boat at 30 knots, which relies upon her great speed as a means of protection when charging upon the enemy. As the submarine when submerged cannot hope to overtake its target it must lie in wait for the target to come to it.

Thus limited to moderate surface speed and low submerged speed, and unable to increase weights by the addition of armor, the submarine is obliged to rely upon her faculty for concealment as her chief means for employing her weapon, whether mine or torpedo. But concealment entails disadvantages. In hiding herself she becomes blind, and if by the adoption of the periscope she has recovered partial sight, she has sacrificed a corresponding measure of invisibility. Before concealing herself to attack, the submarine first must sight her enemy in order to direct her attack. To accomplish this to best advantage she must rise and search the horizon with natural vision. Unfortunately when so doing she cannot promptly submerge and is therefore liable to surprise attack. The submarine's difficulty in seeing has consequences which extend beyond the individual ship. In warfare there is a combatant advantage in superior numbers which is greater than the numerical ratio of the hostile forces (as may be mathematically shown). For this reason it has always been reckoned a great point, both ashore and afloat, to bring superior forces to engage simultaneously upon the field of battle. But the submarine's imperfect vision occasions danger of interfering with friends when large submarine forces are concentrated for simultaneous concerted action, such as does not occur in the assemblage of any type of surface craft.

Thus the submarine is not only an arm to be used by stealth, but its most favorable opportunities occur in dispersed and solitary action rather than in concentrated and co-ordinated action.

Having thus glanced at the offensive and defensive capabilities of submarines we may now turn to the means of parrying their attack and of overcoming it.

Until the outbreak of the current great war there seemed to be no adequate defense against submarine attack, but necessity is the mother of invention in tactics as well as in material, and there is less to fear from the submarine now than at the outbreak of the war. The great ships which the submarine would most gladly meet find their best protection is rapid motion; for the slow submarine, seeing imperfectly, is disconcerted by swift movement, more especially if this be accompanied by frequent alterations in direction. But ships cannot be always on the move, and it is necessary to provide both passive defense and active counter-attack against submarines. For harbors and certain sea areas the passive defense is furnished by wire nets

whose meshes are of a size suitable for catching submarines, while the counter-attack is made by thousands of swift patrol boats whose business is to destroy the submarine or force him down again whenever he comes to the surface for information or for air to start his engines and to recharge his batteries.

The success of these measures against submarines is undeniable. At the beginning of the war German good fortune with submarines promised the most important results, but as the war drew on the efficacy of submarine warfare diminished as methods of reply to it developed. It is now an important arm, but not the supreme one. By a line of *a priori* reasoning the general broad conclusion to be drawn from this survey is that the submarine is essentially a defensive arm, whose use as an offensive arm, although practicable, yet partakes somewhat of the nature of a *tour de force.*

After this brief review of the general qualities of submarines and the probabilities open to them we are ready to take up the consideration of the particular types of submarines best suited for American use. Preliminary to this examination it will be desirable to summarize the accomplishments of the submarine under the conditions imposed by the relative situations of the present belligerents.

The early performances of German submarines caused them to stand very high in popular estimation, but they have not yet been able wholly to justify the expectations they first aroused. The efforts of Germany to wrest the control of the sea from the grasp of Great Britain and her allies called for the exertion of the highest type of offensive war; but, as we have already seen, the submarine, in its essential nature, is the defensive weapon of the weak. It met with a temporary success, first in the North Sea and later in the Mediterranean, which in each case lasted only until the entente allies had time to prepare counter measures. At the opening of the war British ships advanced boldly to the German side of the North Sea and maneuvered there at slow speeds. The hostile submarines took advantage of their opportunity and the British forces withdrew from the vicinity of the German coast. Great Britain then developed the net defense of her ports and of the cross-channel routes to France, as well as the counter-attack against hostile submarines and mine-layers, by the patrol flotillas of whose work such an excellent idea is given in Kipling's "Fringes of the Fleet." After six months of warfare, the Germans began their submarine attack upon commerce. The strategic features of this phase of the war need our consideration.

German submarines were charged with the aggressive task of destroying commerce, but owing to their essentially defensive nature they were obliged to lie in wait in positions where shipping would come to them. The favorite area was that between the south of Ireland and the western entrance of the English Channel, since nearly all British foreign commerce naturally took that way. But as the Straits of Dover were protected by nettings the Germans were obliged to pass around the north of Scotland to reach their station, a distance of about 1,200 miles. Once there, it was necessary to lie on station some days in order that the time at work might be in reasonable proportion to the time needed to make the trip and return.

Thus, as a matter of logistic economy, the submarine employed on this service required a large radius of action which entailed a considerable size—about 800 tons. Our attention has been particularly centered on these large craft because their deeds attracted most notice, but they are not the only ones employed. We have every reason to believe that, where submarines are needed for their proper defensive rôle to protect the German coasts, much smaller ones are used. Similarly, the English, who have the mastery of the sea, yet need submarines to aid in the protection of their ports against sudden raids, make use of small ones. We know this because they have bought such boats in the United States, and a number of them held at Boston for delivery after the war are now to be seen there.

So far as we know, submarines have accomplished little or nothing during the current war when acting in company with the main fleets. At the battle of Jutland last May they seem to have been absent or ineffective.

The evidence of the present war as to submarines may be summarized by saying that on both sides they have obtained a degree of success in defense, to the extent of forbidding the approach of the main fleets of both sides to hostile coasts. In this successful coast defense, submarines have been greatly aided by mines.

The use of submarines for the purpose of strategic attack has been less successful, although Germany's attack, in particular, has arrested much attention. The submarine strategic attack has been chiefly directed against commerce, by the British and Russians in the Baltic Sea against German trade with Sweden, and by the Germans at the entrance to the English Channel against the ocean trade of France and Great Britain. While this destruction of commerce has been serious, it has not led to conclusive results, although the narrow waters in which this contest has taken place have been favorable to the efforts of submarines because commerce has been obliged to cross the areas infested by them.

In estimating the value of submarines in the current war we must not attribute the present shortage of commercial shipping wholly to the deeds of submarines. In the order of their importance the factors in this shortage seem to be:—First, the great military and naval demands made upon commercial shipping; second, the internment at home or abroad of all or nearly all shipping of the central powers; third, the delays imposed upon allied shipping by the patrol and mine-sweeping services which have adopted a retardatory but necessary administrative system for the protection of ships passing through dangerous areas; fourth, the actual loss of shipping caused by submarines which seems to have been about 3 per cent a year, more or less, nearly the same the English merchant service encountered without serious consequences in the Napoleonic wars.

The foregoing discussion has had the objective of placing us in a position to consider what type of submarine will best suit the requirements of our own navy, and this we shall now proceed to do.

The geographic situation of the United States, with a very extended coast-line, much of which is remote from possible enemies and borders great oceans, is very different from that of the present combatants, who are separated by comparatively

narrow waters and confront each other at relatively short ranges. As we have seen, the submarine is essentially a defensive arm. It finds least opportunity when it meets its enemy in the open sea with full freedom for maneuver. On the contrary, the submarine is favored when its enemy approaches a hostile shore, where his freedom of maneuver is hampered by the proximity of the coast and his advantage of speed is thereby partially counterbalanced.

Therefore it does not seem desirable that our navy should attempt to establish a defensive cordon of submarines far from our coasts in mid-ocean. For a line held there will be long; its distance from shore will require much time to arrive at and return from station, necessitating excessive numbers of ships. The enemy has no objective in mid-ocean and will not wait there. If he is attacked in that neighborhood by submarines, he has the advantage of full opportunity to maneuver freely at high speed. On the other hand, our submarines will gain on every one of the above-mentioned points if they are used for local coast defense and do not go far off shore—say not more than a day's run. They may well expect to maintain a strip of coastal waters fairly free from the enemy and available for coast navigation, as do the English at the present time.

Thus the size and type of coast-defense submarine of about 500 tons now favored by our Navy Department seems the proper and logical one for American use. It is true that it is a much larger type of submarine which has obtained most press notice in the current war, but that is because the requirements of the situation were such that the areas best suited to the operations of German submarines were far from German bases. We do not foresee any strategic reasons that will require our submarines to operate so far from home. American coast defense does not appear to require the largest type of submarines. Nevertheless, the appropriation act of this year calls for three of a large size (800 tons), which will prove instructive and useful as experimental boats even if they prove to be larger and more expensive than necessary.

There is a great desire on the part of every navy to provide submarines capable of accompanying the fleet and taking part in general actions. For such a purpose a second type of submarine is necessary.

Such a craft will be away from its base for a longer time than coast-defense submarines and must therefore have a larger crew and better quarters. Tactically, also, its requirements must be quite different. As was earlier pointed out in this paper, an automobile torpedo has a greater virtual range when it is fired to meet an approaching target than when it is fired to overtake a retreating target. Consequently an ideal torpedo-boat, whether of the surface type or of the submarine type, should have superior speed to that of its probable opponent in order that, however the latter turns, the torpedo-boat may assume an advantageous position ahead of the enemy before closing to discharge the torpedo. But this is a difficult condition to satisfy with a fleet submarine. The standard speed of battleships reached 21 knots some years ago, and is now on the rise once more. At present 23 knots may be regarded as the normal speed for foreign battle-

ships of the most recent design, and our navy should not lag behind others in this respect. An ideal fleet submarine should have both surface and submerged speeds not less than 25 knots, and a submerged radius of at least two hours at maximum speed. Unfortunately, we cannot get a quart into a pint pot, nor is such an ideal fleet submarine practicable. No submarine, even of as large size as 1,200 or 1,500 tons, can get sufficiently powerful machinery into her; first because her hull weights must be great to withstand submergence, and, second, because she must be provided with two heavy systems of motive power in place of one lighter one, such as surface craft have.

In the present state of engineering we shall therefore be obliged to content ourselves with a surface speed approaching the cruising speed of the fleet under war conditions, or about 20 knots. The submerged speed and radius must be very moderate; sufficient only to serve as a means of passive defense by concealment, but not enough for aggressive maneuvering while submerged. The mechanical limitations thus imposed upon fleet submarines restrict very greatly the tactical freedom of the commander-in-chief who attempts to utilize submarines in a general engagement. Other component elements of the fleet are all capable of acting in mutual support of each other in aggressive attack upon the enemy. The fleet submarine, limited as it is in speed, is incapable of such co-operative attack with other types, for it cannot force itself into the fight. The commander who seriously relies upon his fleet submarines in a general action must place himself upon the strategic defensive and so restrict his freedom of maneuver as to make it a chief objective to draw the enemy within the pre-established area of the submarines. It is clear that such a limitation is a severe handicap. It is nevertheless desirable that our fleet should be accompanied by submarines for use when opportunity serves. Those now building are abreast of present possibilities, but should be improved and developed in succeeding years as engineering progress dictates. The chief distinguishing characteristics for them are high surface speed with adequate surface endurance and habitability. High submerged speed and great submerged radius are comparatively secondary affairs unless most radical improvements are brought about in the methods of submerged propulsion, so that high submerged mobility may be obtained without undue sacrifice of surface mobility.

The conclusion to be drawn from this study is that the Navy Department has made a judicious decision in the combination of military characteristics which it has embodied in its latest designs of submarines for service with the fleet as well as for coast defense.

DISCUSSION.

The President:—This interesting paper by Captain Rodgers entitled, "On the Suitability of Current Designs of Submarines to the Needs of the U. S. Navy," is now before you for discussion.

Professor W. Hovgaard, *Member*:—Captain Rodgers especially emphasizes the defensive nature and capabilities of submarines and from this premise makes his deductions as to their use and the best type to be adopted. He conceives the principal duty of the submarine of the United States Navy to be local coast defense, and concludes logically that boats of 500 tons displacement should be the standard type. Beyond that, Captain Rodgers recommends only one type, the so-called fleet submarine, which is of the largest size that can be efficiently constructed, probably of from 1,200 to 1,500 tons submerged displacement.

Now it must be borne in mind that one of the most serious shortcomings of submarines is lack of endurance. It appears from the experience of the European war that even for large boats the maximum time of continuous sea service under war conditions is about three weeks, if the efficiency of the personnel and *matériel* is to be maintained at a reasonable standard. This limitation is imposed, not so much by the quantity of fuel or the number of torpedoes which the boat can carry, but more by the physical endurance of the crew. It is clear that larger boats are in this respect superior to smaller, being more seaworthy and roomy and allowing much in the way of comfort which must be denied the crew of smaller vessels. The period of effective service is, therefore, considerably shorter for smaller boats than for larger. This point is of particular importance for the submarines of the United States Navy, because their service lies chiefly on the open ocean, even when on patrol duty near a base, and the distances to be covered along the extensive coast lines of the country are very great.

Speaking first of defensive warfare, the most important and typical case from a strategic and, perhaps I should say, academic point of view, is a war with England, for this is the only country which single-handed can force a strictly defensive attitude on the United States Navy. I am, in fact, referring to this case merely as a strategical possibility—not as a political probability—but no study of the strategic conditions of this country would be complete without considering it, however remote it may be. If the navy is prepared to meet this contingency, it is prepared to meet all.

Apart from local coast defense, for which submarines of 500 tons or less will be suitable, and of which undoubtedly a great number will be required, the United States Navy in such a war would need boats that would carry out a vigorous aggressive defensive. It would be necessary to have boats which could harass the blockading fleet—not only the small, fast vessels stationed near the shore, but also the large blockading ships, which would probably keep going at a great distance from the coast. Submarines would be required also for blockading or watch duty off Halifax, the Bermudas, Nassau, and in summer time in Cabot Strait, and even in the Strait of Belle Isle, about one thousand miles from the nearest base of the United States. In the Caribbean Sea, Jamaica, Trinidad and other points would have to be watched, and in the Pacific, Vancouver. If the Panama Canal fell in the hands of the enemy, submarines would be wanted for its blockade at both terminals. Submarines would be required finally to operate in conjunction with the fleet when it made sorties. For all these duties, most of which require long voyages and protracted service in the open sea on stations far from the base, large boats are needed, not necessarily of the size of fleet submarines, but probably of at least some 800 tons displacement. Smaller boats would be unsatisfactory for such service, because they could keep their station only for shorter periods and would thus require frequent relief.

In a war against a coalition of other powers, the navies of which are in the aggregate superior to that of the United States, large submarines will again be needed for attack on the lines

of communication of the enemy, and on the advanced bases which he might possess, or which he might seize.

Consider now the case of a war in which the enemy is a distinctly inferior power, perhaps separated from the bases of the United States by several thousand miles of ocean. Here, again, large submarines will be useful. The only case where small boats can be used is where the United States is in possession of a secure advanced base near the enemy's coast, but at present no secure advance bases are found as against any naval power.

Although very reluctant in expressing an opinion at variance with that of the distinguished author of this paper, I cannot avoid the conclusion that in defensive as well as in offensive warfare the United States will urgently need a great number of moderately large submarines, that is, boats like the British E-Class, the German U 33-42 type, or the type designed by Mr. Spear, described under the name of Type B, 1914, in the paper on submarines which he read last year before this Society. All these boats are from 800 to 900 tons displacement, but it is quite likely that, as in the case of other warships, this type will tend to grow still larger in the future.

Captain A. P. Niblack, *Vice-President*:—My remarks are intended not so much a discussion of this paper as a somewhat broader discussion of the question of submarines. Captain Rodgers, as a former president of the War College, and a recent member of the General Board, is in a position to discuss this question thoroughly from the standpoint taken in the paper. My remarks have in a measure no bearing on his paper, but apply to the lecture we had last evening in Mr. Ewertz's presentation of the submarine question.

I want to present a point of view which I think it is important a Society like this should take, and that is not the sentimental one, but the intelligent, intellectual one. I have been asked by many persons—many of whom I was surprised should ask the question—if I did not think the submarine was a cowardly, dirty weapon of warfare. I have replied that I did not see quite how, as a naval officer, I was in a position to say that or acquiesce in it, since our navy has been the one to develop the two types of submarines now used abroad by the two principal powers which are engaged in this war. The Holland type of boat was sold to the British Government, and was developed originally by Sir Philip Watts, and later by others, into quite a different boat, of course, from the original Holland boat. The Germans were much later in taking up the submarine question, and they preferred the Lake type, so their boat is a development of that type.

Now there is no country in the world quite as interested as we are in the development of the submarine, and it would be a great mistake for us to get entirely too sentimental on the question. It is entirely a business proposition, and in all we do and say, and in all of our actions, we should be careful not to tie our own hands in the future, because we are certainly relying on the submarine as a weapon of warfare.

I want also to present a point of view which I have arrived at in regard to submarines, and that is on this and all naval questions we take too much of a defensive attitude. We are always waiting for someone to kick us. Of course, if you get the defensive idea very strongly in your head, you are always thinking of the other fellow who is coming over to get you, and what you will do about it. That is not the way to design and build a navy. You must design it on the principle that you are going over to get the other fellow. That is the way you will end the war, for that is the only way wars are ended.

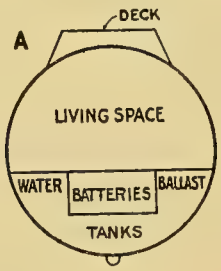
With reference to the submarine, we must adopt the offensive idea, and not take any

other, and this thing of sitting back, as here, in New York, and relying upon some guns and mines and submarines to protect us, is all very nice, but it has nothing to do with warfare. I am in favor of the larger type of boat, because I think we ought to have the very best fighting, habitable type that can be obtained. I am in favor of that general proposition. In other words, we must look at this thing from the standpoint of the man who, when he goes out for the other fellow, is going to get him. That means crossing the ocean.

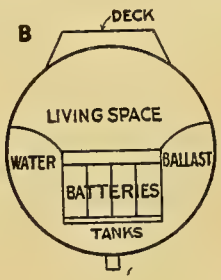
Just switching this idea to a consideration of types of submarines, with the apology that I know very little about the subject, I will show you how little I do know about it by some sketches I will make on the blackboard. I made a trip in the original Holland in 1898. I had just returned from Germany, where I had been a naval attaché for a year and a half, and I subsequently went back to Germany and was naval attaché for another year and a half just before the war came on, and I was particularly delighted with the development of the Lake form of submarine in Germany.

In the original Holland boat you had a cigar-shaped cylinder, in which you had the submerging tanks at the sides and bottom and the living space was what was left (diagram A).

American Development of the Holland Type.



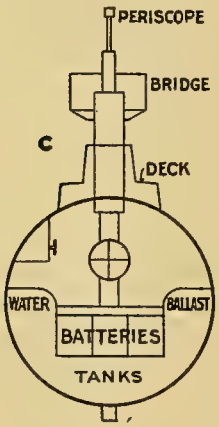
1900



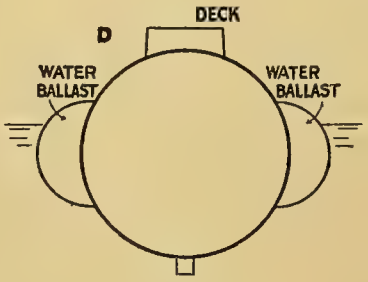
1913

This largely gave the required strength, with self-contained units, so to speak. The later boats, in order to get quicker submergence, used larger tanks, and gave less living space (diagram B). The British development of the Holland type is shown in diagrams C and D.

British Development of the Holland Type.



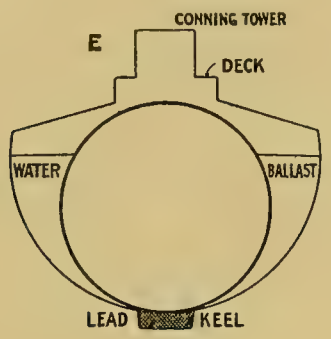
1904



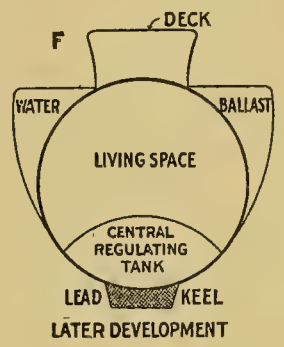
1912

In the Lake type of boat, as originally taken over by the Germans, they had a steel cylinder, and in that cylinder they got all of the space they wanted for machinery, living spaces, and all of the vitals of the boat. I do not refer entirely to her fuel supplies, but I mean the vital parts of the boat. Around that cylinder they built the body of the submarine itself, the boat, and gave it any form they pleased (diagram E).

German Development of the Lake Type.



1905



LATER DEVELOPMENT

The great trouble with the original Holland design was the shape of the hull, as we all know, and the difficulty of getting speed with such a shape. The Germans pounced on the Lake idea, saw it was a good thing, and built around the cylinder a boat in which the whole cross-section was anything you like. I will put a fancy yacht form on it (diagram F), but it can be anything you like. In the outside hull they put the tanks for submergence. Or, to draw it a little more accurately, they gave a neat form to the boat like that (indicating diagram F) and had the tanks and water ballast and other things in the exterior hull. Giving it such form as that (indicating diagram F), the boat had good maneuvering powers.

I do not care to commit myself on the question, because I am not well enough informed, but I have always had a great fancy for the Lake type of boat and the German idea, and to show how sound the German idea apparently is, they are every day putting the submarine securely on the map. We must not forget that. I mean to say that it is not very good policy for us to discredit the submarine in the sloppy way we do in the newspapers. I am not speaking of any moral conception, but the status of the submarine is something we are interested in in having established definitely as a legitimate weapon of warfare, otherwise, why not ourselves give it up?

We are now building sixty-nine new submarines, and this is not the time to talk about great moral issues, because those things are settled by international law. I am speaking of the question of policy. If we can get out of our heads the idea there is anything necessarily illegitimate about the submarine, we have made a long step in advance.

In reference to this question of the central cylinder, I am not an advocate of the Lake type of submarine necessarily, but I am only trying to give the general impression that you get a sea-going type of submarine with the German idea, and it is rather more difficult to get it with the other type of boat. Fortunately we have both types in our service. We had the rights to develop both, and for this country later we will get from the contending belligerants very important data as to both types of submarines. Personally I only express my re-

gret that in our navy we have not balanced the two types a little better as to numbers. I do not think we have quite favored one side as much as we have the other.

Mr. W. L. R. Emmet, *Member of Council:*—I was made chairman of the Committee on Submarines by the Naval Consulting Board and thought it my duty to inform myself somewhat on the subject. Although I have not come directly in contact very much with such vessels, my experiences and inquiries have led to a few generalizations on the subject.

I have in the course of my association with the Navy Department in connection with turbine propulsion work for several years past come in contact with three or four different submarine experts who were serving in the department at different times. These gentlemen are possibly serving as navigators now, and other navigators are in preparation for the submarine expert job in Washington.

This is not a criticism of the Navy Department, but it is a sort of suggestion of the fact that the Navy Department is, it seems, hardly doing enough to develop such a complicated engineering problem as the building of submarines. To do anything with such a problem, the most expert engineers must devote a vast amount of time and attention to it, and a great deal of money must be spent upon its development and perfection.

As I have looked at the submarine situation, it seems like a fruitful field for engineering activity, and the impression which I have formed is that our navy seems a little too much disposed to regard the submarine as having arrived, that certain types have been developed, and that those are the ones to build. It seems to me there are enormous possibilities in the submarine. One little detail which came to my attention the other day was this—I have talked with several different submarine experts in Washington concerning the possible propulsion of submarines by steam instead of by oil engines as a measure of simplification, a slight possible disadvantage in fuel consumption being incident to the use of steam, but a very great mechanical simplification. I have always been told that while they figured on it a little, it was impossible and could not be considered, and that there were various good reasons for not doing it.

The other day we had a visit in Schenectady from the Glasgow representative of the British Thomson-Houston Company, which is our English branch. He told me they had furnished blowers for forty steam-driven submarines built within the last two or three years in England. These boats are about 12,000 horse-power each, and many of them were at sea. He reported they were very successful and that he had been informed by the authorities in the British Navy that such boats were considered vastly superior to the oil-engine-driven boats and that they were not going to build any more of that type. My information may not be exactly right, but it is so strikingly different from what I hear on the same subject at Washington that it seems rather significant.

There is another matter which I have considered in connection with submarines. I find there is nothing original in the idea, but it strikes me as interesting, and it is this—the storage battery affords a means of storing oxygen and other combustible materials which, being combined, produce electricity. It was suggested a long time ago, I believe, that, as a substitute for the storage battery oxygen be stored in submarines and used for combustion. Recently methods of producing oxygen by the liquid air process have been greatly improved, and theoretically it can be produced extremely cheap in large quantities, and can be stored under pressure in liquid form by methods recently discovered. With a steam-driven vessel it would, I believe, be quite easy to use oxygen for under-water combustion; that is, you could

simply enrich your flame as desired and keep up combustion in an enclosed chamber, pumping out the excess. These are just casual suggestions, but I have looked into the conditions and believe that such things are practicable.

The only way that the navy will ever get anything of that sort is by building the submarines itself, or putting the very highest grade of engineers on the job and spending the money to do it. The submarine problem is a highly specialized demand. It is not a thing which any commercial concern is interested in developing. There are certain submarine builders in this country that get a large amount of business, and have been able and enterprising in developing this art, but the tendency of manufacturing companies engaged in the production of such things is to do the things which are easiest for them, and which they know how to do. They develop a certain kind of thing and want to manufacture that thing. If you depend simply upon somebody outside to give you a submarine, you are apt to get the same thing over and over again, because that is the cheapest and best thing from the builder's standpoint.

Rear Admiral A. W. Grant (Communicated) :—There are two statements made in the paper of Capt. W. L. Rodgers which, if accepted, will set us back in obtaining an offensive submarine type for some years to come. They are:—

1. "High submerged speed and great submerged radius are comparatively secondary affairs unless most radical improvements are brought about in the methods of submerged propulsion, so that high submerged mobility may be obtained without undue sacrifice of surface mobility."

2. "The size and type of coast-defense submarines of about 500 tons now favored by our Navy Department seems the proper and logical one for American use."

From the most authentic accounts of German war submarines of the type of the U-53, we learn that Germany has actually developed a very formidable offensive type of vessel.

This submarine has reliable Deisel engines that give a surface speed of about 16½ knots on a shaft horse-power of about 1,400. It carries fuel sufficient to cross the Atlantic, operate on this side several days, and return without refuelling or repairing. How many surface vessels of war are as capable?

In all late German designs the battery weight and space is a fixed proportion of the total displacement. The U-53 can remain submerged for several days at low speeds. From fairly reliable authority it is learned that the large German war submarines can run submerged at a speed of 8 knots for eight hours and can run at about 2 knots for from seventy to eighty hours.

Submerged radius of action when expressed in time rather than in miles conveys more to one's mind. Submersibility is the submarine's means of attacking an enemy or remaining concealed from vessels it does not desire to attack. A submarine will never travel submerged when the surface is available. It travels submerged, when not attacking, merely to conceal its whereabouts. If we know that a submarine can remain in concealment for nearly 100 hours and during this time can without suffering detection obtain continuous sight of its surface surroundings (except of course at night or in a fog), then we at once appreciate that this is a quality of very great offensive advantage.

Having such a battery as is installed in the submarines under discussion and in the Deutschland, by providing suitably large motors a very high speed can be obtained for a

short time, probably 14 knots for a half-hour. This very high speed is desirable tactically for a spurt in intercepting a fast enemy. The long medium-speed submerged radius will be used to approach an enemy that is unaware of the submarine's presence and therefore sees no reason to change its course.

Great stress has been laid in Captain Rodger's paper on high surface speed. This is considered important for certain services that are being performed in the present war. For attack on warships, however, it is of secondary value. The reason is that a submarine must submerge immediately it sights an enemy vessel, else it will reveal its presence and thereby lose the opportunity to attack. From this time on it must approach awash or even submerged. It may be forced to travel 10 or 15 miles under water in order to deliver a successful attack. Surprise is a corollary to the submarine offensive and is the basis of all offensive strategy. In approaching an area where an enemy force may be operating, it may become necessary, for success, to submerge and approach from considerable distances, even as far as 20 to 30 miles, depending upon the number of patrol vessels with the enemy, the depth of water, etc.

Submarine engines should be, above all, reliable. They are constantly called upon for double duty—driving the Deisel and charging the batteries. In demanding high surface speed, much of this reliability is lost. The consequence is machinery breakdowns, and that naturally means total unavailability. I know of nothing more abject than a submarine with disabled engines. Too much emphasis cannot be placed on the fact that all activities of a submarine, even the preparation of the food, depends upon the readiness of her engines, which are the source of all her power.

Even after advocating high surface speed for submarines Captain Rodgers does not permit them to use it. "Owing to their essentially defensive nature," he says in the paper, speaking of German submarines, "they were obliged to lie in wait in positions where shipping would come to them." If they must only lie in wait, why is surface speed given the major importance? Now if these submarines lying in wait had high submerged speed and consequently considerable submerged radius in both time and miles, many vessels which would otherwise escape would be brought within torpedo range. Furthermore, with reliable engines the submarine will reach its station and be able to lie in wait.

It is fairly well known, and the writer has received corroborative testimony recently, that Germany is building all her submarines of the offensive type; and that she still aspires with sufficient numbers of such vessels to overthrow Great Britain's control of the world's communications. With this accomplished, of what value will be the command of the sea? A great surface fleet cannot be maintained indefinitely if this control is lost. It will defeat itself by its very inertia and expensiveness.

Our problem, in the event of war, is to attack the enemy's control of communications, in order to safeguard our shores from invasion by sea.

The idea of establishing a defensive cordon of coast-defense submarines lacks imagination in the conduct of naval war. It is a defensive policy calculated to do great harm to the nation. National policy may be defensive, but, once war is declared, our action must be offensive. A defensive war strategy leads to nothing. The members of this Society can do no greater service to the state than the instilling of the offensive idea in the conduct of naval war throughout our country. Its psychological effect upon our naval policy will be of great moment.

The defensive idea is now deeply rooted in our minds and has influenced our building program, our war games and maneuver problems; in consequence the initiative is freely given to the enemy forces, our own being assigned a defensive rôle.

The submarine should be considered a weapon for the purpose of extending our sea frontiers. If we build submarines capable of keeping the seas in all parts of the Atlantic and Pacific, then the risk to an enemy expedition will become so great that few nations will accept the hazard involved. Our industrial development and our great resources of material will permit this nation building offensive submarines in sufficient numbers to prevent any one nation from controlling the seas against us. In fact, the development of an offensive submarine has struck a hard blow at the command of the sea by any one nation. A warship or a fleet in any part of the ocean will be in constant danger of destruction from an invisible enemy.

You, gentlemen, can aid this country to obtain the type of submarine a correct doctrine of naval war councils us to build. Help us to develop a Diesel engine of great reliability of about 2,000 shaft horse-power to put in our submarine hulls. The submarine hull we want is known and understood in this country. Germany has made it standard for her undersea vessels—some of you may have seen it recently, represented in the German submarine Deutschland.

Submerged speed and radius of action for these offensive types are merely matters of weight and space provided; storage battery development in this country is sufficiently advanced.

The submarine of 500 tons displacement will not give us our offensive submarine type. It will not aid us in extending our frontiers. As a step in evolution it was needed, but we now have passed beyond. To maintain ourselves stationary, as is suggested in this paper, and accept the passive defensive idea is not the true mission of our submarine policy.

Naval Constructor T. G. Roberts, *Member* (Communicated) :—This paper is timely and appropriate, where a viewpoint from the uses of submarines may be pitted against that of their design and construction.

The shipbuilders will no doubt be gratified at the conclusion reached in the paper that the coast-defense type is more suitable for the needs of this country, since any radical departures bring abnormal responsibilities upon their shoulders, as they are required under the language of contracts to guarantee novel results in new and untried dimensions and speeds.

The author's conclusion is identical with mine, as the result of a careful analysis made some time ago when there were so many conflicting opinions afloat. There has been an accumulation of data and ideas here at the Fore River Shipyard in Quincy, which has been the central submarine building plant in the past, and the opinions and reports and testimony of officers as they have occurred have passed in review, and it may be of particular interest to mention the case of at least one eminent tactical expert who completely reversed his original opinion in favor of the coast-defense type to that in favor of the larger vessels, and this out of the same information, as modified by other considerations to be mentioned later, from which Captain Rodgers has deduced the opposite conclusion.

At the outbreak of the war, being in London, I read in the daily papers the account of the first German submarine destroyed in the war, which was by the British cruiser Birmingham, by gun-fire. It seemed the submarine in daylight was maneuvering, submerged, with

periscope, to torpedo the cruiser, but the periscope was discovered and struck by a shell, springing a leak in the submarine which forced her to come to the surface only to be sunk by gun-fire. That was the first lesson in the "limitations of a life" for submarines in the day when Sir Percy Scott's prediction that submarines would overmaster battleships was ringing throughout England and America. The great number of people who became adherents to that view is evidence of the general lack of knowledge of those times. Since then the experiences of the war have shown how weak and vulnerable submarines are in face of an enemy who has adequate command of the surface, especially in the comparatively shallow waters of the North Sea; and yet how powerful a force as influencing the moral factor for the purposes of coast defense, and for forcing a complete revolution in the strategy and tactics of the attacking fleet. The last mentioned considerations are of sufficient consequence to assure the shipbuilders that submarines have come to stay; and the coast-defense type, for operation in limited areas, if adopted as our standard, would entail large numbers. This is already forecast in the last Naval Bill, reflecting, as it does, the views of the Navy Department as expressed in the testimony of the Secretary of the Navy, the Chief of Naval Operations, the General Board, and the Chiefs of Bureaus, whose conclusion as to the coast defense type was the same as that reached in the present paper. Of the soundness of that conclusion there seems no doubt, not only for the leading reasons enumerated by Captain Rodgers but also on account of the fallacies contained in the arguments of those who have recently advocated the larger vessels of 800 tons displacement. A perusal of the testimony before the last session of the House Naval Committee will show the division of opinion sharply drawn between the department on the one hand and the fleet and submarine flotilla on the other, the latter contending that only vessels of the 800-ton size should be built out of the moneys carried in the bill, and this view was shared by practically all officers attached to submarines in service or building. It is well to remember here that this conflict of opinion was very pronounced and took a leading place in the minds of those most concerned with the preparation of the last Naval Bill, so much so that anxiety was felt, no doubt, by officers in general, lest out of such conflict of views the question might become so confused as to result in the withholding of further appropriations until the matter of size should be settled.

There was unanimity of opinion as to the advisability of building the three so-called fleet submarines of the Schley type at 1,106 tons displacement, which were regarded as sufficient for experimental purposes, and the idea conveyed by the adoption of this type was in imitation of similar vessels built in Europe which were reputed to obtain the high speed of 20 knots. Speed was to be the principal desideratum and the object was to create a submarine that could travel with the fleet. As a matter of fact, the best estimates at present indicate that these vessels will probably be able to make as much as 19 knots, but are hardly expected to make 20.

The advocates of the 800-ton size predicated their conclusions upon the reported operations of German submarines of that size which, as Captain Rodgers has shown, were built to operate at a considerable distance from home shores, in an aggressive action. The quality of the information offered in support of what the German vessels had done appeared to be largely hearsay, coming, in one case, from an American boy returned from Germany where he had been impressed for a short time on a German submarine, in another case from information from an escaped sailor, and in other cases from information the sources of which have not been given. It is probable those sources of information are not wholly reliable, especially as to particulars, and it would not seem sound to base any important conclusion

thereon. Furthermore, the literature presenting the arguments for the 800-ton boat indicates it to be the estimated average which European nations are now building; whereas little enough is definitely known of what they really are building, and the deduction therefore seems of doubtful accuracy, upon that basis also, in the absence of any better evidences than those cited.

The claims made in favor of boats of the 800-ton size were to the effect that two 800-ton boats could, between them, keep a station 300 miles from the coast, which would require three coast-defense boats of the "K" class to do the same work at equal costs; that two 800-ton boats at $1,500,000 could keep a station 600 miles from the coast, which would require four coast-defense boats, costing $2,000,000; that two 800-ton boats could keep a station 1,200 miles from the coast which would require ten coast-defense boats, costing $5,000,000, to do the same work; that each of the larger vessels had a round-trip seagoing radius of action from its base of twenty-one days as against ten days or two weeks for the smaller boat; that the larger boat possessed more comfort for the crew and was not limited in its supply of provisions and battery re-watering facilities, as in the smaller boat, permitting the above-mentioned greater radius of operation; that the smaller boat was limited to return to its base after an absence of ten days for re-watering the batteries; that the provision supply of the smaller boat was limited to a maximum radius of action of ten days; and that the discomfort of the crew at sea in the smaller boat was too great to be endured owing to seasickness from greater rolling and pitching, to smaller air-breathing spaces full of fumes and gases, and to smaller freeboard for airing the crew on deck in heavy weather. I have drawn up a tabulation of the various elements affecting these conclusions from all classes of existing vessels, between the H class of 358 tons and the Schley of 1,106 tons surface displacement, and have deduced therefrom, and from other data, the following conclusions:—The internal volume of free air spaces is 7,500 cubic feet on the H class, 9,360 cubic feet on the L class, and 21,400 cubic feet on the Schley. As to the breathing of internal fumes and gases, it is believed from experience on board under way in vessels ranging between the relatively ancient Grampus and Pike, of many years ago, with their noxious fumes and gases that could hardly be endured, and the most recent vessels that are comparatively clear of such gases, that on the whole there will be little difference as between the sizes of boats under discussion; in the submarine of today the noxious gases have varied not in proportion to displacements or free air space, but in proportion to their modernity, where the liquid containers and ventilation systems have been so perfected in the recent types that this question is no longer to be compared with the adverse conditions on the older vessels. As to provisions, a calculation made on the basis of the standard designed allowances shows that for the H class the regular stowage lockers will contain a supply sufficient to last the regular complement sixty days. Similar figures for the L boats indicate fifty-five days, and for the Schley, thirty-nine days. The variation is not altogether inversely in proportion to the displacement but generally so, and the smaller vessel, with its greater radius of action, possesses a greater advantage in that regard. These calculations do not allow for provisions stowed upon the decks inside the vessel, but such stowage is entirely feasible and would be desirable and available, if need be, to extend the radius of action of the vessel, which could be made much more than the above figures indicate—far beyond the distance allowed in the compilations of the desired stations for coast-submarine defense during war. As to re-watering the batteries, distillers are being installed, a fact evidently not then known to the recent advocates of the 800-ton boat, and the limitation in fresh water for re-watering the batteries may be entirely eliminated and the ves-

sel's radius of action extended indefinitely in that regard, in case these distillers do not prove defective at sea, in which event fresh-water carrying tanks can be constructed. As to the comforts of the crew, the seasickness due to pitching and rolling would probably be about equal in the sizes of boats under consideration, the free air spaces for living purposes would not make very much difference between the complements that would vary in slight proportion with the sizes of vessels, and it has been found by experience that vessels such as the L class of 453 tons displacement possess excellent seagoing and sea-keeping qualities (a fact probably not available to the flotilla at the time, as these vessels were just then going into commission), especially in the matter of rolling and pitching, and of sufficient freeboard to air the crew in all weather.

On the other hand, the comparisons made between the two classes as to extreme radius of action for station keeping have been obviously based upon conditions of maximum efficiency of the crew. I think herein lies a fallacy, as the resultant cruising radius is so small as to indicate that the coast-defense type is unsuited to make long voyages under any conditions. As a matter of fact, such a conclusion is negatived by the number of instances where the same crew has remained aboard a submarine during long voyages in our service, as well as the recent example of the British boats going from Canada to England under their own power. Seasickness is undesirable but is no life-and-death matter, and it is obvious that the hardships of warfare on a coast submarine will not be as great as have been experienced in the trenches during the present war, in the field during the hardships of the Civil War or during the Revolutionary War, or in fact as compared with the hardships undertaken by soldiers in any war of consequence. It would seem that a better estimate of the performance of submarines should be made upon the maximum hardships which may be endured under conditions of war, at least for any purposes of reaching maximum radii of operation. The estimates that have been made on these considerations are theoretical in the absence of any actual experience for a tryout at sea, which has never been made.

Now we arrive at the question of speed, which is the crucial point, I think, upon which the advocates of the larger boat have predicated their conclusions in the main. This will be shown by one of their assertions as follows:—"There is but one good reason for building submarines at such displacement (800 tons), namely, high surface speed." This is followed by an assertion that such a vessel would be expected to make 18 to 20 knots. Mr. L. Y. Spear, vice-president of the Electric Boat Company, in his paper read before the Society last year on "Submarines of To-day and To-morrow," stated that such a vessel should make 17 to 18 knots. The Chief of the Bureau of Steam Engineering testified that he expected it to make 16 knots—all on surface displacements. It is my estimate that 17 knots would be the approximate figure that could probably be attained. Similar arguments on the basis of high speed have been advanced by other officers, and high speed is really what the officers of the fleet are aiming at in advocating the larger boats, the other assertions being merely subsidiary considerations for argumentative purposes; and of that there is no room for doubt in view of the oft-expressed aim to use such boats in the operations of the fleet where the war-board game has shown them to be so effective an instrument in a theoretical sense. I understand war games have been played on the board with models of submarines accompanying the fleet with the result of playing havoc with the enemy's forces, assuming fleet submarines to be the equivalent of a torpedo-boat destroyer for night attack, covered with a mantle of invisibility by submersion for daytime defense. An ex-

amination into the various elements constituting these two classes, the destroyer and the submarine, will show that they are direct opposites, the former having all the qualities and attributes conducive to high speed and the latter all those conducive to low speed, and it is not likely that these two types can be merged in the future sufficiently to accomplish the aims above indicated. The views of all officers are united in desiring a high-speed submarine, and that is in the minds of everyone who advocates enlarging these vessels either to 800 tons or 1,200 tons; but for practical purposes it cannot with certainty be guaranteed in the present state of the art—and every surrounding consideration leads to the belief that such a happy consummation need hardly be expected, although it should not preclude all reasonable efforts to perfect the instrument in an experimental way to every extent and to the very limit. Now we are in a position to see that the coast-defense submarine possesses a very much greater radius of action than that conceded by the advocates of the larger type and sufficient to extend our submarine defenses far off the coast-line if need be; but in view of the strategical reasons advanced by Captain Rodgers in his paper, his arguments are believed to be absolutely sound that the conditions existing abroad which made the 800-ton type desirable do not fit into the conditions existing with respect to any probability of warfare on these coasts, and that such extended radii will not be needed. It is my opinion that the best boat yet developed for all our purposes is the coast-defense type—the O class, of 520 tons displacement, now being laid down—as it embodies all of the best elements of the foregoing classes and is sufficiently ample for all purposes from any considerations now in sight.

The President:—I had hoped, as a layman, with a very superficial experience and knowledge of submarines, though sufficient to prevent me from going into the business at my time of life, that some of the experts would have told us how a 250-ton or 300-ton displacement submarine, like the Deutschland, can carry 750 tons of cargo. They have not given us this information. It is a simple matter, I find, and perhaps will come out some time and be given by someone who knows more about the subject than I do.

Mr. Simon Lake, *Member*:—Just as I came into the room, Captain Niblack was referring to the German type of submarine—I understood him to say the German-Lake type. I think, for the reputation of America, I should like to explain certain things and say why I prefer to call it the Lake type as adopted by Germany. Before doing that, it is necessary, perhaps, for me to step away from the scientific discussion of the subject and refer to the business side for a moment to make my point clear.

When the Russo-Japanese War began representatives of both the Japanese Government and the Russian Government came here and inspected our submarine boat, the Protector, which was built in 1901-1902. At that time we had designed two other types, which had both also been submitted to our own Navy Department in 1901; one was called a submarine cruiser, which is practically the type which is being built to-day by Germany and all of the European countries, with the exception of England, and even England has adopted some of the characteristics of the cruiser type above referred to.

The characteristics of that type were, as stated, the submergence on a level keel by the use of hydroplanes—the change from the old cigar-shaped form of submarine into a ship-shape form, with a light-weight superstructure or outside skin, which surrounded a heavy pressure-resisting body, which pressure-resisting body we have always preferred to keep circular, or substantially circular in form, for the purpose of resisting the external pressure

of water; we have also discovered that a shipshape form of hull was much more seaworthy than the cigar-shaped form. That came about by an experience which I had in bringing the old Argonaut from Norfolk, Va., to New York. As originally built the Argonaut was of the usual cigar-shaped form, with a small, non-watertight superstructure. One time I got caught out in the November storm of 1898, which some of you may remember, and in which I believe about two hundred vessels were lost. I found that the cigar-shaped form did not rise to the seas and that the seas would wash over her so that I was forced to tie myself to the conning-tower, and we were not able to open the hatch for some hours. Otherwise the vessel would have foundered, as solid green seas came over the conning-tower at times. She was run by internal-combustion engines, both on the surface and submerged; she had an intake and an exhaust mast made of pipe in an A-shaped form 50 feet high—I speak now of 50 feet from her keel—so we could run on the bottom or under water up to a depth of 50 feet while using our gasolene engines. We could draw the air in the forward mast and exhaust it out of the after mast, so we had no trouble as far as running the boat submerged under engines was concerned, but I remember it was distinctly unpleasant cruising in freezing weather with the greens seas washing over one. We did not reach a harbor in the horseshoe back of Sandy Hook until about three o'clock on the night of the storm, and before I could get down below, after we got into quiet water, my clothes froze stiff on me.

That led to a modification of the Argonaut by adding a shipshape form to her in the form of a buoyant, watertight superstructure. Those of you who saw the Argonaut in the early days would hardly distinguish her from a surface vessel. We thus increased her surface buoyancy when cruising in the surface condition from about 12.5 per cent to over 40 per cent, and then she rode to the seas the same as any surface boat and was as comfortable in surface cruising as any surface vessel. We spent considerable time afterwards in cruising in this boat, with a crew of several men, who lived aboard for months at a time, even during the winter, and we always found her very comfortable.

Another feature afterwards developed by us, which has been adopted by Germany as well as some other nations, was a method of increasing the metacentric height of the boat. As previously stated, the early submarines were practically all of the cigar-shaped form. In 1901, I think it was, I applied for and took out a patent changing the cigar-shaped form by raising the axis both forward and aft (see Plate 73). Through experiments and calculations we found that, comparing this new form with a cigar-shaped form of vessel of the same dimensions, in a boat of about 100 feet in length by about 14 feet in diameter, at the midship section, we succeeded in increasing the metacentric height of the vessel in the submerged condition from 10 inches to 16 inches. The mere changing of the form of hull from a spindle or cigar-shaped form to the form shown here (see Plate 73) increased the metacentric height 6 inches; in other words, with the same boat we got 16 inches metacentric height and much greater stability than was possible to get with the cigar-shaped form. In my judgment, maximum stability is the most important thing in connection with the design of a submarine boat for safe submerged work, and I do not believe you can get too much.

Now, to make this comparison plainer, if you take a cigar-shaped hull built of plating of sufficient weight to just about submerge the hull,—the center of buoyancy and center of gravity lie in the axis about here (indicating). It would now be possible to submerge that vessel and rotate it like a squirrel rotates its cage; or, if a member of the crew moved forward or aft, the vessel would stand on end. In other words, the vessel would have zero

stability. But if you take the same vessel built of the same total weight of material and change it to this form (indicating) and reduce the thickness of material in the smaller diameters so that the hull is uniform in strength and capable of withstanding the same submerged pressure, the center of gravity and center of buoyancy of the vessel would both rise but the center of buoyancy would rise the more rapidly and would be about here (indicating). So we have a vessel of the same weight of construction and capable of resisting the same pressure of water when submerged, because it is composed of the same circular dimensions, but we would find it had a considerable amount of stability due to the fact that the center of gravity and buoyancy, instead of being in the center of this spindle, both at the same point, would be at some other point considerably higher. It has worked out in the actual design of a submarine of the same length and diameter, so that it made a difference of 6 inches; in other words, we got an increased stability of nearly 50 per cent simply due to the change of the form. We believe this form is also better than the cigar-shaped form for surface speed as it tends to reduce the bow wave.

Now Captain Niblack referred to the German type of boat, which resembles more our old Argonaut or some of our Russian designs than it does our present-day boats. The original design which I submitted to the Navy Department in 1893 was a double-hull boat—that is, with an inner and outer hull, the space in between being divided for the main-water ballast tanks, with the machinery placed low down in the hull, for the purpose of getting greater stability, and I am not sure but what that is a better design than some of the later ones, although I do not know of any boat ever built that way.

The object of having the double skin is, in case of puncture of the outer hull to prevent the foundering of the vessel. In some of our later designs of boat we accomplish almost the same thing, having our superstructure extend down over the inner ballast tanks, but there has been a great difference of opinion among naval architects as to the proper width of the superstructure.

The Germans have kept to the general form of the old Argonaut in having a superstructure wider and longer than the inner pressure-resisting hull, while other designers have reduced its width with the object of getting increased submerged speed.

The submarine Protector was shipped to Russia in a special ship. Other Lake type submarines were shipped by the Hamburg-American line vessels. They were unloaded and re-shipped at Hamburg, so that the Germans had ample opportunity to inspect these boats. One of the large German shipbuilding companies took a contract from the Russian Government to build three boats on a modified Lake design, as they understood it from published descriptions and otherwise, but they made one mistake in that design—they attempted to get too great a speed and made the lines of the boat a little too fine and carried heavy flat fuel tanks in the superstructure, which had to be filled either with fuel or water to prevent collapse when submerged. This increased the top weights to such an extent that the boat lacked stability. I was informed she submerged at an angle of about 45 degrees in Kiel Harbor and stuck in the bottom so firmly that they had to get tugboats to pull her up.

In the meantime we delivered the Protector and five other boats to the Russian Government, all functioning satisfactorily.

After the German boat had been partly rebuilt three times I was asked to go to Germany for a consultation with the managers of Krupps to see if I could advise them how to correct their trouble. After a consultation with Admiral Barandon, who was the head of the Krupp

Germania Werft at Kiel at that time, I was able to explain to them their difficulties and advise how to correct them. I was informed they made these corrections and the boats functioned properly.

Shortly after this they brought out the U-1, Germany's first submarine, which vessel was built on the same lines.

About this time a proposition was made by the Krupps for a partnership arrangement with my company with them in Germany, Russia, and also in Italy. I negotiated a contract with their managing director, Mr. Otto Exius, and others of their directorate, which contract their directors passed on and approved, and I sent that contract to America to be approved by my directors. They did not approve it for several months. The conditions and terms of that contract were that they, the Krupps, were to pay us 6 per cent on all submarines built in Germany, 12.5 per cent on all submarines built in Russia, and 7½ per cent on all submarines built for Italy.

After the success of the Lake type over all competitors in Russia, the Russian Government wanted me to put up a plant there and Russian officers promised the ground and also the capital to build a plant, but I did not care to live permanently in Russia as I had a family of two daughters and a son growing up and wished to return to my own country and secure recognition of my inventions here. Consequently, Krupps agreed to build the plant and manage it, I to act in an advisory capacity. My directors, however, did not accept the Krupp contract, on the ground they did not think it advisable to place others in competition with us on a 6 per cent basis. I said that if they did not, the Krupps would come into competition with us anyhow, and we would get nothing, and that is exactly what happened.

When I returned to Germany, after spending some months trying to get the consent of my directors to the contract, Krupps' attorney said, "Mr. Lake, we are very sorry. We have investigated the German patent situation and we think that you have not protected yourself by patents in this country as you have in the United States; we are free to build the Lake type of boat in Germany, and we are going to do so." They have done that ever since. Possibly, under the circumstances, any government is justified in using any means they find available for the protection of their country, and as things are turning out it looks to me as if the submarine is the thing which Germany has got to rely upon for the purpose of bringing about a settlement of some kind, and I believe the submarine is going to be the instrument that will eventually bring about peace between these different countries.

I do not believe there will ever be another maritime war after this one. I think the submarine will prove that no country can longer claim to be mistress of the sea, that the sea is a highway that every nation shall have the privilege to send their ships over and to transport commerce, on equal terms with every other nation.

The submarine is peculiar in the fact that it is able to prevent the carrying on of commerce, if necessary, but it is useless for invading purposes, as the moment any portion is exposed on the surface it becomes vulnerable. It is a peace-making weapon, for that reason. You can build guns to meet guns, aeroplanes to meet aeroplanes, and you can destroy life and property with various other instruments,—and this has always been done from the time when human beings made their weapons of stones and pounded each other to death. But up to the present time the submarine is the first weapon that has ever been invented that has the peculiar capacity, in the prosecution of maritime wars, to defend, or to attack surface vessels on the high seas, but at the same time cannot be used to invade a country, because the moment a submarine shows her conning-tower above the surface she is vulner-

able. As long as submarines remain below the surface they are invisible, and when we get noiseless machinery, which is the next step, you can neither hear them nor see them, and they have the ability to discharge a torpedo or to plant a mine which will destroy any fabric which can be made to float upon the surface of the water. I think our own experiments in our own Navy Department, if they were made public, would prove that assertion. You might armor a ship, or might make her with many different decks and of cellular construction, as many engineers have tried to do, and yet the explosion of a thousand pounds or more of trinitro-toluol, or some similar explosive, would, I believe, blow the fabric either to bits or up into the air. It is absolutely impossible, in my judgment, to build any fabric that will float on the surface that cannot be destroyed by means available to the submarine.

What does this mean? It means that all maritime peoples must get together and make an equitable agreement for the carrying on of commerce. They have to agree and keep on agreeing.

Assume that some one nation refuses to enter such agreement. Will she send a submarine out and destroy the commerce of the others? No; because it will be possible for all the other nations to ostracize her; it will not pay for her to do it. In addition to that, she would not be able to send out any of her own surface ships, as the submarines of the other countries would lie off her port and prevent her carrying on any commerce. That is what is likely to happen within the next year or so in the case of our own ports, in my judgment, unless the present warring nations make peace. I have not any inside information, or anything of that kind, but that is the logical thing to do; therefore I believe it will come to pass. I believe the fact of the U-53 coming to Newport was simply an object lesson, and in articles which I have written I have pleaded for the United States not to become so angry over injuries by war-maddened people as to put us in a position where we could not send out any commerce of our own, because half a dozen vessels of the U-type could stop our sending foodstuffs and the necessities of life to those innocent people on the other side who are suffering for the aggrandizement of a dynasty, or in the interest of commercial supremacy. I think it is our duty to the world to hold ourselves neutral, absolutely neutral, so that when they get to the point, as I believe they are in many places now, of starving over there, we will still be able to send foodstuffs and to hold the respect of all of the nations of the world, including those now involved in war, until some agreement may be made whereby they can themselves prevent the starvation of their women and children. (Applause.)

Now, in regard to the offensive submarine, I hope the time for its use will never come to this country. We can build them, however, if necessary, when we get a proper engine. Admiral von Tirpitz, when I first saw him and showed my plans of both defensive and offensive submarines to his officers in 1905, said, "We are not interested in the defensive submarine; it is the offensive submarine we are mostly interested in." They have been developing that type of submarine ever since. I do not believe it is necessary for us to build submarines with the idea of offense, and for that reason I am in favor of the recommendations which I have heard read of Rear Admiral Grant that we should restrict our policy to building submarines for purely defensive purposes, although defensive requirements may lead to larger types than now exist which are capable of meeting the enemy in their own waters.

Mr. E. H. Ewertz, *Member*:—I just want to say, gentlemen, that we seem to forget the main object that is before us in this talk about submarines. The general public, in their own mind, have a more definite idea about the submarine, how it should be built and handled, than you realize, even though the greater portion of them do not understand the subject in either its technical or practical aspect.

Professor Hovgaard spoke of the mobility of the submarine with reference to impressing upon you the necessity of building large boats for offensive work and for the comfort of the men. It is a fact that boats of the smaller coast-defense type have sailed from Canada to England, from there to the Mediterranean Sea, and have operated in the Sea of Marmora, covering the distance to the entire satisfaction of their governments, and we also know that German coast-defense submarines have sailed down to the Mediterranean Sea and operated there.

It is a misconception to class the coast-defense boat as a type unsuitable for people to live in. People can live in them, but naturally they are not as comfortable as the larger boat; still, we are not building submarines for comfort, but for the service they can render our country.

As far as the offensive boat is concerned, I believe with Captain Niblack that we should build this type as fast as our experience will permit, but let us protect our country first of all by building the defensive boat. We are facing a condition to-day which is a shame to this nation of ours relative to national protection, and the least we can do is to build such a type of boats as we are thoroughly familiar with and thereby place ourselves in a position so that we can protect our coast-line, a condition that we are not in to-day.

We all agree that the government should take the initiative in the development of submarines, which it has not done in the past, for if it had not been for a few strong-minded men like Mr. Holland and Mr. Lake and others who have been interested in submarines, where would our submarines stand today? It is through the efforts of such men that the submarine has been brought to such a high point of efficiency that is has to-day, and the least we can do is to put our shoulders to the wheel to help these technical and commercial men to build boats for the protection of our United States.

Naval Constructor R. D. Gatewood, *Member*:—It is not, I want to say again, the constructor's job to decide what type of submarine we shall build. It is our job to build whatever type someone else decides is necessary. The question at issue, as I understand it, is what type is necessary. Captain Niblack indicated one type as opposed to the type described in this paper. In this connection I want to state that I was at luncheon about three years ago in Italy with Mr. Laurenti, a gentleman and engineer over there who corresponds to our Mr. Lake, or to the French M. La Boeuf. During the luncheon there was a discussion as to the relative merits of four types of submarines—250 tons, 500 tons, 800 tons, and 1,200 tons—and Mr. Laurenti in his very expressive way commented upon these types as follows:—"Two hundred and fifty tons—very good type of coast-defense boat; you need plenty of them, and everybody should have them. Five hundred tons—that is a hybrid; no good; no one should have them. Eight hundred tons—very good; we should have them (meaning the Italians). Twelve hundred tons—better still. Not for us, for other people."

That was his sizing up of the submarine situation as it was then and pretty much as it is now. It is interesting, for his position in the submarine world is a very high one.

As regards specialization, a point brought out by Captain Niblack—they specialize in the work in which Mr. Laurenti is chief engineer to this extent. If any workman or anybody in the plant, or in the country, brings up any question in connection with submarine design, the matter of the location of a valve stem, or the location of a certain cock, the size of the valve stem, or what not, this matter is given careful consideration, not by an assistant, a draughtsman, a foreman, or some other employee, but by Mr. Laurenti himself, and all the plans are carefully studied by him. Better still, in the case of a boat under construction, he will go to the boat and examine the particular section in connection with the change as proposed, or examine a full-sized model of the section made in wood. He sits down in the section, studies all the surroundings, and decides on the merits of the thing, made in wood and put in exactly the place as recommended. They have specialized to that extent—a much greater extent than we have specialized here.

As regards the size of submarines, I would like to ask Captain Niblack as to what he would do in the case of the Panama situation. Captain Hovgaard brought up the Panama Canal situation very forcibly in his supposed war with England. I am interested in the Panama situation, as I expect to go there. I would hate to think of myself at Panama, at war with England. You could imagine the condition we would be in there, with two terminals, and not a base within eight hundred miles, and the Panama Canal closed up as far as offensive operations were concerned. We must have boats which can go to sea and stay at sea, and go to other bases if Panama is closed up, and operate from those other bases as against Panama.

The President:—We will now call on Captain Rodgers to close the discussion on his paper.

Captain Rodgers:—I am disposed to accept Mr. Roberts' remarks, which Secretary Cox read, as a basis of my reply. I am, of course, well aware of Admiral Grant's views as to the type of submarine which I have heard him advance before the General Board in Washington, but hitherto he has not been able to convert either the General Board or the Navy Department to his views.

The coast-defense submarine of 500 tons seems to be necessary to protect the rear of the offensive fleet in its work abroad. The proper line of defense begins at the enemy's coasts, provided we have sufficient force and control of communications behind it. In order to render the control of communications entirely complete, we must be secure at our own bases, and for that we need local defense of individual ports, which is sufficiently carried out by a small type of submarine operating on a small radius, and our 500-ton boat is able to do that quite satisfactorily. The larger type of boat comes in for the offensive operations which Admiral Grant wants. It goes with the fleet, and it is as fast and as large as the constructive abilities of the nation enable us to make them.

As to the Panama Canal, and the defense of it, in case of a possible war with England suggested by a previous speaker, the English ships, or those of any hostile European nation, in going to the Panama Canal would have to pass our bases at Porto Rico, Guantanamo and Key West, and a little farther over, New Orleans. They must pass inside our defensive lines and control all those points as they come in. Our protective operations would be conducted at those points by the local defense boats, while our big submarines would go abroad with the fleet and operate across the ocean as occasion might require.

The President:—As I have remarked, this has been a most intensely interesting subject and one that should be given very much more time than we have been able to devote to it. I have no doubt that you will all agree with me that Captain Rodgers is entitled to our sincere thanks for bringing so prominently before us the subject of submarine warfare at the present time.

We will now adjourn to meet this afternoon at a quarter past two o'clock. The Council will meet immediately after the adjournment of this meeting to elect twenty-nine more applicants for membership, which will make over one hundred at this meeting.

FOURTH SESSION.

Friday Afternoon, November 17, 1916.

Vice-President W. M. McFarland called the meeting to order at 2.15 o'clock.

The Chairman:—Before we resume the reading of the papers, the Secretary will read to you a list of names of candidates recommended for membership in various degrees in the Society.

The Secretary:—The Council held a special meeting during recess to consider the question of new applications for membership, and it is gratifying to know that there are quite a number. The following names have been favorably passed on by the Council for election to the grades of membership indicated, and they are submitted to you with the approval of the Council:—

Members (20).

Charles F. H. Almy, Vice-President and Secretary, Almy Water Tube Boiler Company, 178 Allens Avenue, Providence, R. I.

Morgan Barney, Naval Architect, 29 Broadway, New York, N. Y.

Oscar F. Barrett, Barrett Line Tow Boats and Barges, St. Paul Building, Cincinnati, Ohio.

Everett D. Burton, Tank Shipbuilding Corporation, Room 3330, 120 Broadway, New York, N. Y.

John M. Carson, Manager, Crymes Engineering Company, Fort Morris Street, Jersey City, N. J. Post Office address, 25 Monticello Avenue.

Leigh H. Coolidge, Naval Architect, 66 West Marion Street, Seattle, Wash.

James A. Davies, Engineer, Marine Department, Westinghouse Machine Company, East Pittsburgh, Pa.

Horatio N. Herriman, Manager, Great Lakes Department, American Bureau of Shipping, Rockefeller Building, Cleveland, Ohio.

Herbert T. Herr, Vice-President and General Manager, Westinghouse Machine Company, East Pittsburgh, Pa.

David Kidd, Assistant Chief Draughtsman, Hull Division, Lake Torpedo Boat Company, Bridgeport, Conn. Post Office address, 3288 Main Street, Stratford, Conn.

Gottdank L. Kothny, Manager, Marine Department, C. H. Wheeler Manufacturing Company, 18th Street and Lehigh Avenue, Philadelphia, Pa.

Herbert E. McConnell, Engineer, Tank Shipbuilding Corporation, 120 Broadway, New York, N. Y.

Charles K. Myer, Surveyor, American Bureau of Shipping, 66 Beaver Street, New York, N. Y. Post Office address, 519 South Orange Avenue, South Orange, N. J.

John W. Stewart, care of J. W. Isherwood, 17 Battery Place, New York, N. Y.

Ingvald Tonning, Ship and Engine Surveyor, 17 South Street, New York, N. Y.

Ignacio Toro, Lieutenant, Chilean Navy, 56 Victoria Street, Westminster, London, England.

Walter A. Windsor, President, Marietta Manufacturing Company, Point Pleasant, W. Va.

F. W. Wood, General Manager, Maryland Shipbuilding Plant, Bethlehem Steel Company, Sparrow's Point, Md.

Frederick L. Worke, Superintendent, Luckenback Steamship Company, 931 Foster Avenue, Brooklyn, N. Y.

Frank Wright, Surveyor, Insurance Company of North America, 27 William Street, New York, N. Y.

Associates (5).

Sydney B. Carpenter, Vice-President and General Manager, Brunswick Refrigerating Company, New Brunswick, N. J.

Eliott Curtiss, Secretary-Treasurer, The United States Metallic Packing Company, 429 North 13th Street, Philadelphia, Pa.

Frank M. Hiatt, Draughtsman, Bureau Construction and Repair, Navy Department, Washington, D. C.

Robert A. Sheerin, Mechanical Engineer, 41 Chestnut Street, Flushing, N. Y.

Joseph D. Tomlinson, Superintendent American-Hawaiian Steamship Company. Post Office address, Cranford, N. J.

Juniors (4)

Frank de Ganahl, Tank Shipbuilding Corporation, 120 Broadway, New York, N. Y.

Charles F. Gross, Instructor, Marine Engineering, Naval Academy, Annapolis, Md.

Edward G. Sperry, Engineer, Sperry Gyroscope Company, Manhattan Bridge Plaza, Brooklyn, N. Y.

Carl E. Wilsberg, Draughtsman, Lake Torpedo Boat Company, Bridgeport, Conn. Post Office address, 405 Seaview Avenue.

The Chairman:—Gentlemen, you have heard these names recommended by the Council for membership and associate membership in the Society. Will some member make a motion to approve the action of the Council?

Mr. Elmer A. Sperry:—I move that the report be adopted and the action of the Council be approved.

The Chairman:—The Secretary has an important matter to bring before the Society. It has already been before the Council, and the Council desires to have some expression of opinion from the membership.

The Secretary:—This is a matter which it was expected would be presented by Colonel Stevens, who promised to be here at this time. He is anxious to have it brought before the Society, and as he is not here I will state the subject-matter of the recommendation which he has made, and which has his hearty approval.

The question has been brought up to the Council by several members of the Society as to the advisability of the Society of Naval Architects and Marine Engineers establishing what might be called a Code of Professional Ethics to regulate the status of practicing naval architects.

It is thought that this is a matter which could be properly handled by the Society, and which would be of benefit to the naval architects of the country. The matter was discussed at length in the Council meeting held the day before yesterday, and the Council recommended the desirability of such a code, and that it be submitted to the Executive Committee, which was to appoint a special committee to take entire charge of the matter, with power to act. That is the recommendation of the Council.

THE CHAIRMAN:—Gentlemen, you have heard this recommendation of the Council, and, as I said in bringing the matter before you, the members of the Council after discussing this matter themselves desire to get an expression of opinion from the membership. Will the members who desire to say anything concerning this subject please do so. It is a very important matter. You know that this question of professional ethics is one that nearly every large society, similar to ours, has had under consideration, and many of them have established a code which governs the members of the society.

One of the questions involved is that of fees. A professional code establishes the fees, and when a member of the Society, or any professional man acting under it, renders services of a certain kind, there will be no dispute as to what his compensation shall be, because the code determines the fee.

PROF. C. H. SADLER:—To bring the matter before the meeting, I move the adoption of the recommendation of the Council. I think it is a very important matter, and I am sure we would all be very glad to hear what various members have to say on the matter.

THE CHAIRMAN:—The question is before the house on the motion to adopt the recommendation of the Council. You understand what that means, that the matter is to be left to the Executive Committee, with power to act and to appoint a special committee to prepare such code.

PROF. W. HOVGAARD:—I think it would be well if the chairman would inform us more in detail what the Council has in view besides the question of fees which has just been mentioned. There are other points.

THE CHAIRMAN:—Colonel Stevens has made a tentative draft of the headings for the code, and it will give you some idea of what he has in mind if the Secretary reads it.

THE SECRETARY:—I will read the matter submitted by Colonel Stevens. It is as follows:—

DRAFT OF REPORT ON CODE OF PROFESSIONAL ETHICS FOR SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS.

The formulation of a code of professional ethics for marine designers presents special difficulties. Conditions surrounding the practice of the profession in this country differ not only from those usual in Europe, but also from those prevailing in other branches of engineering in this country.

The systems of regulation that are proving successful in other professions are the results of growth. In all cases they depend for their vitality on the body charged with the interpretation and application of the principle to the special cases under consideration.

It would seem wise, therefore, at this time merely to formulate in general terms those

principles it is desired to enforce, and to provide the necessary machinery for that purpose, leaving further development and refinements to be established by precedent and experience.

The following statement of principles and outline of powers are respectfully submitted:—

I. It is declared unethical—

1. To criticise the professional standing or work of any fellow-member.

2. To do any professional work without making a charge therefor in accordance with the established schedule or to conceal any such charge by combination with other charges.

3. To accept any valuable consideration from any person connected with professional work except as client.

4. To bring any suit arising out of professional relations either against fellow-members, clients or employers without the approval of the Committee on Professional Ethics.

5. To transact any professional business otherwise than becomes an engineer and a gentleman, or so as to bring discredit on the profession.

II. Unethical behavior may be punished by admonition, either secret or public, or by suspension, in the discretion of the Committee on Professional Ethics, or by expulsion on vote of the Council, but only on the recommendation of said committee.

III. A Committee on Professional Ethics shall be appointed yearly by the president; it shall consist of five members; it shall have power to interpret and enforce the principles of professional ethics; it shall establish a schedule of maximum and minimum charges for professional services; it shall advise members inquiring as to any doubtful matter of professional ethics; it shall keep a record of its proceedings, and shall report to the Council such matters as it deems should be made public.

No member of said committee may act in any matter in which he is personally interested, of which fact the committee shall be the sole judge.

There shall be no appeal from any finding of said committee.

The Chairman:—That is a general expression of the general scope of the proposition, the details to be worked out by such committee as may be appointed.

Prof. W. Hovgaard:—I think it is a most excellent move, and I wish heartily to recommend it. I second the motion made by Professor Sadler.

The Chairman:—Is there any other gentleman who has any comments to make? Gentlemen, you have heard the motion. All in favor please say "Aye"; opposed, "No." The motion is carried unanimously.

The next item of business on our program is paper No. 11, entitled "Naval Stations and Naval Bases," by Capt. A. P. Niblack, U. S. Navy, Vice-President.

Captain Niblack presented the paper.

NAVAL STATIONS AND NAVAL BASES.

By Captain A. P. Niblack, U. S. Navy, Vice-President.

[Read at the twenty-fourth general meeting of the Society of Naval Architects and Marine Engineers, held in New York, November 16 and 17, 1916.]

It is important that this country awaken to its strategical requirements in the Atlantic, Pacific, and Caribbean, and, as the principles governing the selection and outfitting of naval stations and naval bases are not generally recognized, it is the intention here, as briefly as possible, to touch on the elements of the problems awaiting us. That type of statesmanship which attains its highest ambition in securing a naval station as a local improvement at national expense, and that type of citizenship which secretly hopes that there is some cheap, honorable, and unannoying way of saving the nation at reduced rates will derive cold comfort from the actual facts.

There are special considerations, in the case of this country, which require clear recognition:—

1. We are the only country facing equally on two great oceans with full responsibilities on each.

2. We are, in our relations with other powers, practically an island with widely outlying colonial possessions in the Atlantic, Pacific, and Caribbean.

3. We are committed to the policy of forming no alliances, and must go it alone.

4. We are the sole remaining country not to adopt the principle of universal military service as being synonymous with the great democratic principles of equality before the law, equality of opportunity, and equality of responsibility.

5. We are the sole remaining country in the world in which the coast defense is not entirely, or almost entirely, in the hands of the navy.

6. We are the sole remaining victim in the whole world of the voluntary military system which is enormously expensive per unit, prohibitive in the cost of providing "adequate" personnel for the land and sea forces, and foolishly extravagant in pensions, in the cost of recruiting, and in the inducements, pay, and "bounties" which it is necessary to offer.

7. A large percentage of our population consists of undigested and unassimilated foreigners of whose individual loyalty we must entertain serious doubts.

When naval and military authorities are confronted with the task of drawing up war plans, in time of peace, they must ask themselves a lot of questions such as the following:—

What is the best thing to do, not with what we ought to have, but with what we actually have and can expect to have?

Is our particular policy which threatens trouble in a given locality, or with a given nation, vital to us, and does it threaten a vital interest of the other nation?

Would a war in support of such policy involve us with other countries?

How far will it be necessary for us to go to force our policy on the other country, and, in case of war, to what limits would our people be willing to go to continue it?

Would both nations throw their entire strength and resources into a fight to the death—that is to say, would the war be a limited or unlimited one?

Are there local (domestic) or foreign (international) complications which will force us to adopt a defensive strategy, or may we count on an offensive, or what would ever be in our case, situated as we are, an offensive-defensive?

In case of war, shall we attack at once or leave the initiative to the enemy?

May we plan to fight with the nation as a unit behind us, or may we expect interference and confusion from local politics, or indifference and lack of public sentiment to sustain the war?

Let us, however, assume that wise statesmanship, patriotic sentiment and national spirit are back of us.

Fortunately, in times of profound peace, naval strategy in the unobjectionable form of peace strategy enables us to absolutely forestall the possible actions of other countries in any given area, and, while enforcing our own policy, may make resistance or war inadvisable on the part of another country which may oppose such policy. Thus has the British Empire been consolidated.

We recently, by treaty, secured control of the Nicaraguan canal route with the necessary terminal bases at the Corn Islands in the Atlantic, and in the Gulf of Fonseca in the Pacific. We have, in our actual possession in the West Indies and in the Pacific, absolute treasure islands of strategy for the location of those advance and outlying bases necessary to supplement the fleet we are building, which will jointly guarantee us that measure of command of the sea as will give us the national security which we all crave and which, at this moment, to our peril, we actually lack. It is merely a question of intelligently willing to do it, and then putting up the money. In doing it, in time of peace, we offend no innocent country, but we might bring on a war by undertaking even a small part of it during a time of strained relations. No one waits until it rains to begin repairing the roof.

To establish ourselves securely within the political areas in which our manifest destiny lies not only removes temptation from other countries to try to overreach us, but protects us from that danger to ourselves which comes from using strong diplomatic language without the real power to make it good. The siren and lulling words of interested countries are not a safe foundation on which to build the national defense.

To outline our peace strategy, let us assume that, among all our navy yards and stations on the Atlantic coast, our two main bases, to be decided upon, are, say, New York and Norfolk. New York, as the assumed center, and Boston and Philadelphia on the periphery of the circle enclosing the main industrial area of

the United States, become the true strategical center the instant we deepen the Cape Cod and the Delaware and Raritan canals into ship canals, clear the East River of all obstructions from the Battery to Long Island Sound, and adequately fortify Block Island, Vineyard Sound, Buzzards Bay and Cape Cod Bay regions. With exits at Delaware Bay, Sandy Hook, Block Island, and Massachusetts Bay the entire British Navy, as it exists today, could not contain our own navy as it is, although it is continually able to contain a much larger and more powerful one, the German Navy, even with the two exits it has by virtue of the superb Kiel Canal. Our "Heligoland," Block Island, is now only a summer resort, but, defended as it should be, it would be the armed sentinel at the gate. The region around New York, of which we speak, represents billions of dollars, and the expense of providing mobility to our naval forces and security to the area would be but a fraction of one per cent. As a mere commercial proposition the enlarged waterway would pay without the guns and mines to secure it, in case of war, and the present serious trend of public opinion makes the whole question one of easy possibilities. The defenses of Cape Cod Bay, Narragansett Bay, New York Bay and Delaware Bay are one and the same question, and the area from Boston to the Delaware Breakwater is our main strategical area.

Our second considerable strategical area is that of Chesapeake Bay, embracing Washington and Norfolk—that is, the national capital and an immensely important naval base. It is far along in our plans to speak of the very desirable proposition of the Delaware and Chesapeake Canal as a ship canal, but it is easy enough to see what it would add to the mobility of our naval forces and to the security of our coasting trade in case of war. Just now the adequate defense of Chesapeake Bay entrance is the main consideration, for we have left that "stable door" wide open, as we have also the Delaware Bay entrance. It is therefore idle to talk too much theory when our practice is so elementarily careless.

The first commanding strategical point, in connection with the Panama Canal and its approaches, is Key West. Mahan, in his "Naval Strategy" (p. 317), says, "There is nothing that can be said about the interests of the United States in the Panama Canal, as connecting the Atlantic and Pacific coasts, that does not apply with equal force to the Straits of Florida as uniting the Atlantic to the Gulf of Mexico and the Mississippi Valley." Its main importance is in its relation to Cuba, whose political integrity we are pledged to defend. Cuba is, in effect, as far as Guantanamo is concerned, the absolutely undefended mainland of the United States, since it is up to us to defend it from invasion—and we have taken no steps thus far to do so.

In considering the defense of the approaches to the Isthmian Canal route in the Atlantic and Caribbean, the most striking fact is the commanding position of Great Britain, with Bermuda less than 700 miles from Cape Cod, Sandy Hook, and Cape Henry, and with the Bahamas, Jamaica, St. Lucia, Barbadoes, and Trinidad commanding the approaches to the canal from all directions. While we all habitually assume the benevolence of British policy toward us, it is not a justifiable stra-

tegic assumption. One should not leave his business affairs entirely in the hands of anyone else if it can be avoided. Fortunately we already possess the necessary positions to secure the approaches to the Caribbean against all comers, and all we need is the sagacity to add to the strategical positions the necessary strength, resources, and mobile defenses to make them good. We have the tactical defenses of the Panama Canal itself well under way and well understood; and we have Guantanamo "on the mainland," dominating Jamaica, and the Windward Passage; but we have over and beyond all Culebra Island, the neutralizer of Bermuda and the British West Indies positions—the ideal outlying strategical base—situated 20 miles east of Porto Rico and 20 miles west of the Danish island of St. Thomas. For the price we could possibly purchase the Danish West Indies we could make them useless strategically to anyone else by spending the money on Culebra, only 20 miles distant from St. Thomas.

Almost every drawback that may be glibly cited against Culebra as our great naval base for our fleet in the Atlantic is really an advantage. For instance, it is usually argued that the island and its harbor are too small, whereas, if anything, the island is too large, and the harbor could be even smaller before it would cease to be ideal. Of course it is out of the question to expect to find a ready-made naval base, and we are in luck to have all the treasures we have. There is above all no question of Culebra versus Guantanamo, because the latter merely supplements the former. There may be a Culebra without Guantanamo, but no Guantanamo without a Culebra, because Guantanamo is on the undefended mainland, and, with Culebra securely held, it would be on the flank of an attacking expeditionary force operating against Guantanamo. As Mahan points out in his "Naval Strategy":—"In short, as to the Caribbean and the Isthmus of Panama, Guantanamo and Culebra can become to the United States what Gibraltar and Malta are to the interests of Great Britain in the Mediterranean and at Suez, with the advantage to us that they are nearer our home ports than those positions are to Great Britain." While statesmen abroad sleep with his books under their pillows, and do not sleep well on that account, the writings of the late Admiral Mahan are not so fully appreciated in our own country.

The Panama Canal defenses, although lacking considerable in gun installation, mobile troops and secret service protection, present the ideal of position, strength and resources, in that it is hardly conceivable that an enemy would be strong enough to operate against it in both oceans at the same time, and we may easily maintain uninterrupted communications by way of either the Atlantic or the Pacific, whichever, at the time, is not under the enemy's control.

On the Pacific coast we recognize the importance of two home bases, one on San Francisco Bay and the other on Puget Sound, and so it remains to consider the question of outlying and advance bases in the strategy of the Pacific. In his splendid book on "Naval Strategy" Mahan says:—

"Through the Caribbean Sea lie the approaches to the Isthmus of Panama, the place where the Monroe Doctrine focuses. The Caribbean still remains important,

perhaps it has not even quite lost its lead, but it is now balanced by the Pacific * * * National policy now imposes naval stations in the Pacific * * * The selected ports, however, in both oceans obviously can and should form a well-considered system, in which the facilities and endurance of each part shall be proportioned to its relation to the whole."

It will be noted that the positions which Germany held in the Pacific are now held, possibly only for the moment, in other hands, thereby upsetting that balance of positions which gave no one country too great a dominance for our own future good. We have, to be sure, recognized the singular strategic importance of the Hawaiian Islands by half-heartedly providing some of the defenses of Oahu Island and Pearl Harbor. Anyone really alive to the actual situation in our Pacific possessions must feel grave misgivings as to our future on that ocean. An ounce of prevention now is worth several tons in the future if our relations became strained, and the remedy lies in intelligent appreciation and conservative but definite action.

Without going too deeply into an analysis of the strategy of the Pacific, there is one thought which we must dismiss from our minds, and that is that we are really ever going to allow anyone to tell us to get out of Guam and the Phillipines, or that the moral and economic interests of the world at large will be otherwise than definitely set back by our doing so. To do so voluntarily is enough like the proposition of removing both hands from a sheet of fly paper to make it difficult to appear graceful in doing so. On the contrary, history will vindicate the acquisition of the Philippines as an act of broad statesmanship, through which we will eventually solve the question of our economic relations with the peoples of the Far East by that exhibition of moral and physical purpose which alone satisfies the oriental mind. Soft words and evasion of issues get you nowhere in diplomacy, and only intrenched position is useful in strategy.

It is an historical fact that no great naval battle has ever been fought in mid-ocean, but always near the bases of one or the other powers, and the ports of supply, or naval bases, indicate the direction of the line which operations must take in time of war and which become lines of communications once the fleet has advanced beyond any one naval base on the route. We already have in the Pacific the heart's desire in strategical positions, and we only seem to lack the knowledge and nerve to strengthen such of them as will permit us to take the initiative and thereby forestall and even prevent war by making it too hopeless for anyone else to take the chances. It is a game of checkers, with our advantage against the whole world as far as mere positions go. It is clearly in our power to compel the strategy of the Pacific in time of peace in such a way as to avoid the possibility of war. Pacifists who preach disarmament as a means of avoiding war are safe enough on the paid lecture circuit, but to be pacific in the Pacific is to be the strong man armed—and there is no other way. That we will ever be so armed in the Pacific no one can believe who recognizes the potency of local and political interests in absorbing the substance which might better go to the maintenance of the two arms of national security, viz., a well-

paid and well-trained diplomatic corps and a chain of naval bases for our stay-at-home fleet.

Any consideration of the strategy of the Pacific is utterly futile which leaves out the erection of Guam into a great naval base as our key to it for all time—our far-flung outpost of "peace in the Pacific" through armed power in repose. Other positions which we now own, such as Tutuila (Samoa), Dutch Harbor (Unalaska), Sitka, Midway Island, Corregidor, etc., are questions of definite offensive or defensive areas, or of shortening lines of communications, and as such are worthy of consideration as strategic points, but our first necessity is the extension of the defenses of the Panama Canal and Pearl Harbor. Then come Culebra and Guam as great insular bases.

Meanwhile the other strategical points above enumerated should be treated, for the time being, as possible advance bases; their harbors should be cleared of obstructions, and the necessary equipment prepared accordingly. Even Guantanamo may be, for the time being, regretfully placed in the advance base class.

The problems of our national strategy are so vast and yet so light-heartedly disregarded that it is essential that naval officers and army officers who know the real situation should have with them the intelligent understanding and co-operation of all intelligent citizens. Half measures give foreign nations a great advantage when diplomatic relations are strained, because they compel a temporizing policy at critical times, for it is then impossible to do anything in the way of hasty preparation, because it will only precipitate war.

An accompanying chart, similar to that in last year's Proceedings of this Society, shows at a glance the outlines of the problem of our strategy, with the Panama Canal in working order. What it would be with the canal blocked is another question. The defense of the canal is therefore the prime requisite of our national policy.

We require naval stations and naval bases to correspond with our policies, with our strategy, and with the requirements of our fleet. It means the expenditure of millions of dollars and is the price of that empire which is ours by destiny, by geography, and by the blood this nation has already shed, but which empire will surely crumble if we sit back.

That preparation in time of peace can only be called adequate which leaves only mobilization as the remaining step in strategy if war unhappily comes. We know what our resources and land and sea forces are, and also those of other nations. We know what our own and other nations' policies are. Our strategy must fit what we have, and if we have little we can do little. The apparent difference of opinion among naval officers as to the needs of the naval establishment, when called upon to enumerate them, is largely merely a difference in the values assigned to the various elements of sea power and the exigencies of the moment, considering how much our strategy lacks in so many directions. At any rate our military and naval establishments are adequate when they—

(*a*) Are superior in *matériel* and *morale* to the corresponding forces of a probable or possible enemy.

(*b*) Correspond with the requirements of the Monroe Doctrine and the defense of the Panama Canal.

(*c*) Answer the main requirements of our strategy.

As one writer expresses it, "The fundamental condition of success in war is harmony between policy and strategy." Policy may be defined as the attitude or course of action of a nation which influences its relations and intercourse with other states, and as examples we may cite, in our own case, the "Monroe Doctrine," "Asiatic Exclusion," the "Open Door in China," the "Freedom of the Seas," and the defense and control of isthmian canal routes in Central America. Strategy may be defined as the assembling, distributing and directing, in any given area of possible or probable hostile operations, of all the armed strength and resources of a nation to best secure the limited and definite objects of a policy, or war growing out of a conflict of policies.

Mahan says, for instance, that the "Monroe Doctrine is only as strong as the United States Navy." That is about true of all of our policies, and it is high time, among other things, that we take up the consideration and study of the question of naval stations and naval bases on the basis of our strategy and the needs of our fleet, rather than on the narrower lines along which such questions are now settled.

DISCUSSION.

THE CHAIRMAN:—Gentlemen, this paper by Captain Niblack on "Naval Stations and Naval Bases" is now open for discussion.

COMMODORE J. W. MILLER, *Vice-President:*—The broad scope of Captain Niblack's paper undoubtedly prevented him from dwelling in detail upon many of the important subjects relating to coast defense. May I be permitted to amplify one?

He touched upon the necessity of bettering the line of defense between New York and Boston.

It has been my good fortune during the past few years to be connected with the building of the Cape Cod Canal. It was begun as a commercial and financial enterprise to afford a safer route for a coast merchant marine equal to what passes through the Suez Canal.

The European war began and the canal at once became, in addition, a military and naval necessity. The sinking of vessels by the German submarine on the off-shore route around Nantucket proves this. The passage of the German steamer Willehad from Boston to New London through the canal, to keep within the 3-mile limit, also confirms this argument.

The sooner we get a marine trench between the Hudson and Massachusetts Bay, the sooner will our populous and richest Atlantic coast cities be insured comparative safety from a hostile fleet.

We forget, in these piping times of peace, the hysterical cry for protection during the spring of '98 when the supposed formidable Spanish fleet was frightening our sea coast towns of this very region.

The few rocks at Hell Gate removed, the 8 miles separating Buzzards Bay from Cape Cod Bay deepened from 25 to 30 feet, a line of mines laid from Montauk to Marthas Vineyard, another from Provincetown to the Massachusetts main coast, and we have an interior perfected waterway in which fighting vessels of all descriptions can rendezvous. Each and all ready to combine within a few hours at any threatened point, and thus forming a continuous second line of defense instead of three separated squadrons or fleets—one at Sandy Hook, one in Narragansett Bay, and another at Boston—which cannot make a junction except offshore and possibly in the face of an enemy.

Our fighting effectiveness is thus increased three-fold, and our mobility by the difference resulting from the 411 miles around Nantucket as against smooth-water navigation of 267 miles through the canal.

The cost of deepening the canal will be less than one-third of that for a battleship, and about the same as proposed for the futile attempt to dredge a fast-filling channel at Pollock Rip.

The merchant marine, humanity, and true patriotic preparedness all demand the improvement of this inland, almost natural waterway. The lessons of the past, the forecast for the future, would seem to warrant no delay in its accomplishment.

I am well aware that certain officers of the navy have limited their view to the fact that the defense of the coast is only an incidental function of the main fleet. This argument may be good from the strictly professsional point of view, but does not embrace a plan based upon joint co-operation of all governmental bodies and looking towards the protection of all interests.

A second line of defense close to our shore may, in the final analysis, spell victory instead of defeat.

The immeasurable benefit to the country at large through an inshore smooth-water route, and the incalculable increase in preparedness resulting therefrom, cannot be overestimated. The reason for this conclusion should be patent to all; certainly to the combined ability of a joint army and navy board, and to the Department of Commerce, which, if asked for its opinion, will, no doubt, in these days of deeper commercial ships, see the necessity of protecting them in time of war as well as of giving them increased safety in time of peace.

Professor W. Hovgaard, *Member:*—I take a great interest in the science of strategy, to which I have given much thought and study. Having lived fifteen years in this country, I naturally have become interested in the strategic problems that confront it, but I wish to have it clearly understood that what I am about to say is offered, not in a spirit of criticism or advice, which would be a presumption on my part, but merely as an objective, academic comment on the paper which is now before us for discussion. I feel the more tempted to take part in this discussion, because I consider the views presented by Captain Niblack as so absolutely sound, and concur especially in the order of importance which he assigns to the various outlying strategic positions of the United States. There are certain points, however, which, in the interest of the national defense, might be brought out more sharply.

I wish first to emphasize the fact that outlying possessions, if not provided with adequate local defenses, and if the fleet is incapable of commanding under all circumstances

the strategic area in which they are situated, must form points of vulnerability, and that hence they must become a source of anxiety, danger and weakness in time of war. This I believe must be admitted to be the case at present with practically all the outlying possessions of the United States, including the Panama Canal, and so long as this condition lasts they are the opposite of an advantage. In a war with a superior naval power, such as Great Britain, or with a coalition of two or more naval powers of superior aggregate strength, all the outlying naval stations and bases are likely to fail in their main object, which is to offer points of supports for the fleet. Instead of that they are liable, like Port Arthur, to become traps for detached squadrons, and will sooner or later fall into the hands of the enemy, as happened to Kiautchau and the other German possessions in the Pacific.

The Panama Canal stands supreme in importance among all outlying bases. Not only is the control and use of this waterway of the utmost direct strategic value to the United States, but its possession by an enemy will be of at least equal value to him. In a war with a superior naval power, like Great Britain, or against two powers, one in the Pacific, one in the Atlantic, it seems very doubtful whether connection could be maintained between the mainland of the United States and one of the terminals of the canal. Most likely both terminals would be blockaded and, since the mobile garrison, unless considerably reinforced beyond its present strength, is entirely inadequate to resist a serious land attack, the fall of the position would be only a question of time. The English could, in fact, bring a practically unlimited pressure to bear on it. If, then, the Canal Zone cannot be held, it will be necessary to render it inoperative, for instance, by letting the water out of the Gatun Lake, but as the lake would fill up again in two rainy seasons—*i. e.,* within a year and a half or two years—it may be found advisable also to demolish the locks in case a longer war is anticipated. When, as in a war with Great Britain or an equivalent combination of powers, the fall of the canal could be predicted with tolerable certainty, it would evidently be wise to demolish the canal and to evacuate the zone at once on the outbreak of hostilities. This procedure would be analogous to the abandonment of untenable positions and the destruction of bridges in land warfare.

The remarks of Captain Niblack on Culebra seem to me extremely interesting and important. The position of this island is indeed ideal, like that of St. Thomas, and it has the additional advantage of being much smaller, and, therefore, easier to defend. It appears also that a much larger harbor can be obtained, although this will, I suppose, involve a very considerable outlay in the construction of breakwaters and other extensive works. Provided no insurmountable difficulties are encountered in such works, Culebra is indeed superior to St. Thomas as a main base, but I believe that the latter island would nevertheless be valuable as a secondary or additional base for light cruisers, destroyers and submarines.

Guam unquestionably takes the first rank as a naval base in the western Pacific. The present fortified positions in the Philippine Islands would be untenable in a war against Japan. Armies can be landed elsewhere on the islands and the positions can be taken from the rear, in the same way as Kiautchau, but a strong naval base at Guam would render such operations on the Philippine Islands extremely precarious.

It is not here the place to go deeper into the highly interesting questions raised by Captain Niblack in this admirable paper, but I will refer to an article which I hope will soon appear in the Proceedings of the U. S. Naval Institute, in which I have discussed the strategic conditions of the United States, first in war with Great Britain and secondly in a war with Japan and Germany.

In conclusion I wish to repeat that when I speak of wars between this country and cer-

tain other countries, I do so entirely from an academic point of view. Nowadays international political relations change as in a kaleidoscope, so that in a strategic study the most important cases must be considered, irrespective of their present political probability.

Captain W. L. Rodgers, *Associate Member:*—I believe that the military value of internal waterways in time of war is overrated by the general public, and therefore I would like to address myself to one point in Captain Niblack's paper, where he speaks of the advantage of an internal waterway between Cape Cod and the Delaware. He speaks of it as an internal waterway and suggests that it is a line of interior communication. I would like to offer something on the opposite side of the position that he takes up.

The line running from Cape Cod to New York and the capes of the Delaware lies along the arc of a circle, and the direct route between the two extremities is a chord. Therefore, in point of distance it has a disadvantage over the direct route and, if it is cut as a canal, it will have not only the disadvantage of distance but additional disadvantage in time on account of the slow speed which only is possible in an internal waterway.

Some experiments were carried out in Germany when they were working on the Kiel Canal and elsewhere, and certain determinations were made as to speed through a canal (the resistance, of course, as everybody here knows, very much depends on the area of the cross-section of the canal) and they found in the case of a cross-section of waterway six times that of a ship, that at a speed of 6 knots the resistance was several times what the ship had in the open ocean. With the cross-section of a battleship, which is now between 2,500 and 3,000 square feet, you would have to have from 15,000 to 18,000 feet of cross-section of canal in order to make a speed of 6 knots with a resistance six times that of the ship in the internal waterway. Any higher speed would be impracticable, so that the time element in concentration would be decidedly against the use of artificial waterways. We have at present a base at Narragansett Bay, and New York and the Delaware Bay are in the center of the industrial region of the United States. Our naval forces at the beginning of mobilization will always be there. We shall then have to mobilize before the enemy arrives on this coast, or else we must use the artificial waterways, if they exist, as a means of mobilization and concentration after the enemy has arrived. A concentration after the enemy is here is too late. He has taken the lead in the game of cards we are playing.

If an internal waterway exists, we cannot do anything until we come out. If we are to come out, we must depend on the submarines and mine fields to keep a free area of ocean for the debouchment of the main fleet in case we are delayed in mobilizing. The same submarines will enable us to keep a free area of ocean for effecting our concentration at sea equally as well as they will enable us to debouch after concentrating by artificial waterways.

The Chairman:—This is a most interesting paper, but we have a very long program, and, unless some gentleman is anxious to say something, we shall ask Captain Niblack if he cares to close the discussion.

Captain A. P. Niblack:—I have nothing further to say.

The Chairman:—I am sure that you will all authorize me to thank Captain Niblack for this interesting paper and the interesting discussion which it has brought out, and in your behalf I do extend him our thanks.

We will proceed to the next paper, No. 12, entitled "Refrigeration and Refrigerator Insulation on Board Ship," by Mr. Robert F. Massa.

Mr. Massa presented the paper.

REFRIGERATION AND REFRIGERATOR INSULATION ON BOARD SHIP.

By Robert F. Massa, Esq.

[Read at the twenty-fourth general meeting of the Society of Naval Architects and Marine Engineers, held in New York, November 16 and 17, 1916.]

INSULATION NOTES.

In the following notes on refrigerator insulation it is the writer's intention to call attention to several elementary physical facts—facts which everyone knows and the regard for which would seem to be engineering common-sense, and yet facts which are very apt to be neglected in insulating cold storage compartments.

Some repair work recently done on refrigerators in a large New York hotel offers an excellent example of how not to insulate a cold room. The fact that this was a stationary installation does not affect its importance as an example of wrong method.

These refrigerators, when they were originally built, were constructed by cementing cork sheets against concrete floor, walls and ceiling, with wooden strips set in the cork. The cork was applied in two layers, each 2 inches thick, the second layer being secured to the first by cement and the strips of wood being set in the last layer applied. To these wooden strips there was secured an inner lining for the refrigerator made of white porcelain-enamelled sheets of steel.

Upon examining this refrigerator after several years' service, it was found that the insulation, particularly in the lower part of the box, was water-soaked, that the steel had been almost completely rusted out, that the wooden strips holding the metal in place had rotted away, and that the moisture had worked down through the floor and was getting into the wine room located directly below the refrigerator.

The defect in this design lies in the fact that it is not possible to fit these enamelled sheets close enough to the cork to do away with air pockets, and, if these pockets exist, the variations of temperature to which they are inevitably subjected mean alternation of pressure within them, and, consequently, interchange of air with the outside, the deposit of moisture and its gradual accumulation.

This deposit of moisture is increased where the cooling surfaces are placed close to the walls of the refrigerator, this action being due to the greater deposit of moisture at the lower temperature, and, further, to the greater variations in temperature to which air pockets near the cooling surfaces are subjected.

This same difficulty of making a perfectly tight wall holds, not only with the white porcelain-enamelled sheets, but with all metal sheets and with glass refrigerator lining. These glass linings are one of the most attractive appearing linings

for refrigerators, but for the above-mentioned reason are not desirable as ordinarily installed.

The method that was used for correcting this set of refrigerators consisted in removing all of the defective insulation, replacing it with pure cork sheets set in Portland cement, using two layers of 2-inch sheets as before, and then finishing the inside of the refrigerators with cement with rounded or cove corners. In this way all air spaces are absolutely eliminated and a practically permanent structure is secured.

There is, of course, a tendency which cannot be avoided for the cement to crack as it dries. This is taken care of by scoring the surface in rectangles so that the cracking occurs on these lines, and after the cement has thoroughly dried these cracks are filled with a paint, *i. e.*, a white enamel paint that is used for a final finish on the surface.

A refrigerator finished in this way is not as attractive in appearance as the glass, or, for that matter, even the porcelain enamel on metal, but it is certainly a more sanitary structure.

Another way to overcome the cracking difficulty in the cement is to give the cork a skim coat of cement, then bed into this either a sheet of expanded metal or wire mesh of some kind, and then apply a final coat of cement. The two layers of cement are used to avoid any possibility of air spaces being left if the metal is secured direct to the cork, and then only a final coat of cement applied.

A further difficulty in the original design of the refrigerators under discussion was brought very forcibly to the attention of the men who did the actual repair work on this job. The work, unfortunately, had to be done while the kitchens were in service, and, although the weather was not especially warm, the men found the interior of the refrigerators so hot that it was impossible to work any length of time without going outside to cool off. Ranges and steam kettles were so close to the refrigerators that there was only space sufficient for the men working on the ranges and kettles to get about them and for a rather narrow passage behind them, *i. e.*, between them and the refrigerators. When one stops for a moment to consider the purpose of insulation—namely, to prevent the flow of heat into the refrigerator—it would seem reasonable to so arrange the building as to reduce as far as possible the temperature to which the outside of the refrigerator is subjected.

In insulating refrigerators that are "built in" on board ship, the best construction with which the writer is familiar is that illustrated in Plate 75. The insulating material—namely, pure sheet cork—is cemented with a special cement directly to the steel surfaces forming the compartment. The second course of cork is set in asphalt after the first course has been carefully pointed up with an asphaltic cement mixed with fine re-granulated cork. In this way all possibility of air spaces is eliminated and the chance of any moisture accumulating is avoided.

The inside surface may, in this case as in the insulation described before, be finished in cement, although in some classes of work the cement can be omitted and an asphalt finish used instead.

One cannot conclude from the suggestion that cork can be cemented directly on to the steel in the construction of refrigerator compartments on board ship that a similar construction is suitable for ice-tank work in stationary plants. In this work the surfaces of the tanks are, in general, not particularly true. There is also the difficulty of rivet heads which must have the cork fitted about them. In work of this size this fitting is apt to be done carelessly, with the result that air spaces will occur and the cork be forced out of place by freezing and melting of moisture.

Difficulty has been encountered, in one or two installations which the writer has seen, with the use of cork that had not been sufficiently pressed previous to baking. This cork was not as dense as it should have been and had not the mechanical strength it should have had. More or less air spaces were left in the cork, into which there was, of course, the tendency for moisture to penetrate, and where the temperature was very low this moisture froze and pried the sheets apart, completely disintegrating the insulation and requiring that the entire work be done over again.

The idea seems to prevail that a refrigerator door should have beveled edges and that these beveled edges make a very tight door. How this idea originated it is beyond the writer's power to divine. As a matter of fact, such a door can be tight only if it happens to be very carefully fitted. As soon, however, as the moisture begins to have its inevitable effect, the door cannot by any chance be tight. Furthermore, if the hinges yield at all, as they are certain to do with a heavy refrigerator door, it will never be tight, even though it does not warp at all.

In the writer's opinion there is only one practical way to make a tight refrigerator door, that is, to have a plane surface come up against a plane surface with a flexible gasket between these two surfaces, as shown in Plate 76. It may also be possible to have a pair of such surfaces, or, rather, two pairs of such surfaces with gaskets between them, making an air pocket between the two seals. If this arrangement is used the door can sag considerably without causing any serious binding or failure in tightness.

This matter of a satisfactory refrigerator door cannot be emphasized too much. Our experience has been that refrigerators built by some of the best known shipbuilders have been fitted with extremely bad doors, thus seriously increasing the difficulty of properly refrigerating the boxes.

REFRIGERATION NOTES.

In estimating the capacity of a refrigerating machine required for taking care of a given refrigerator, it is not sufficient to calculate the heat loss through the insulation of the refrigerator. In fact, this loss in many cases is very much smaller in proportion to the total loss than the average engineer realizes.

It is proportionately so small, in fact, in the case of ordinary household refrigerators that almost all the builders of this class of refrigerator, after comparing the ice consumption in well and in poorly insulated boxes, use very low grade insulation in their stock boxes. Their custom, in general, is to reduce the size of the air passages leading to and from the ice compartment to a very small area and

thus, by restricting the flow of air over the ice, they reduce the meltage to a minimum. The average purchaser of one of these refrigerators is more interested in economy of ice than he is in the temperature to be secured in the box. He assumes that the temperatures are all right, but he knows each month whether or not the economy is right, when the iceman's bill comes in.

Heat enters a refrigerated compartment through five avenues:—First, through the walls, *i. e.,* through the insulation; second, in warm goods; third, by the interchange of air through the opening of doors and by air leaks through defective insulation or through defective doors, cold air being heavier and immediately flowing out when doors are opened; fourth, from lights or from the heat of the bodies of workers; and fifth, from any change of state occurring in the goods, such as freezing, fermenting, etc.

In large rooms these various losses of heat should be analyzed separately. In small refrigerators, such as those for hotels, kitchens, private homes, the average galley refrigerator and so on, a rough rule that gives quite as accurate result as a more elaborate analysis allows for a certain number of British thermal units per cubic foot of refrigerator per 24 hours; for instance, 1,300 British thermal units per cubic foot for an average pantry refrigerator. If the box is located in a kitchen, as in a hotel or restaurant, it is safer to allow about 600 British thermal units; and if the kitchen is especially warm, as many galley kitchens are, 900 British thermal units are safer, especially if the boxes are small.

For butchers' coolers or large boxes in hotels, *i. e.,* large storage boxes from 6 feet by 8 feet to, say 10 feet by 15 feet, a safe allowance is, approximately, 200 to 250 British thermal units per cubic foot for 24 hours. In climates varying appreciably from the temperate zone, corresponding allowances must, of course, be made.

In general, the size of machine for a given refrigerator has to be decided upon before the refrigerator is put into service. On the other hand, where an existing ice-cooled refrigerator is to be cooled mechanically, one check on the size of the machine required is given by the amount of ice which has been used. This check is, however, more likely than any other to lead to wrong conclusions unless the figures are properly analyzed. The following is a suggested scheme of analysis:—

First, determine the average daily ice consumption for the summer months—say, July or August—from the actual weighing of the ice, or from the ice bill.

Second, determine as accurately as possible the average temperature that was secured by ice in the refrigerator. This will usually be from 55 to 60° and, although it is commonly stated as anywhere from 40 to 45°, these lower figures are so seldom obtained day in and day out as to practically warrant the statement that they are never reached. It is only with a full ice chamber and with the box closed for long periods that such low temperatures can be secured, and even under these conditions the average temperature will still run well above these figures.

Third, calculate the heat inflow through the insulation with the temperature in the box as actually observed or as assumed, and with the average summer temperature prevailing outside.

The difference between the heat inflow through the insulation and the total heat actually absorbed by the melting of the ice is the amount of heat entering the box from other sources than through the insulation. This excess of heat ordinarily occurs during the daytime only, *i. e.,* when the box is being opened, since at night the box remains closed. A machine, to be of sufficient capacity to produce the temperatures actually obtained with ice, therefore, must be large enough to obsorb the heat inflow through the insulation and also the additional heat entering during the daytime from other sources, *i. e.,* to take care of this entire load during the day. Stated in another way, the machine must be large enough to absorb, during the daytime part of its run, half of the total insulation loss plus all of the balance of the loss.

Fourth, a further fact to be taken into account in determining the proper size of machine is that the temperatures which are obtained with ice are not satisfactory. If they were satisfactory, one of the greatest reasons for putting in cooling machinery would be void. Where a temperature of 55° can be obtained with ice, 35 to 45° will be demanded of mechanical cooling. Therefore the machine size must be further increased in proportion to the number of degrees difference of temperature required. For instance, if the outside temperature is 71° and the temperature desired is 35°, where the ice temperature has been 55° the machine size must be increased in the proportion of 71 minus 35, divided by 71 minus 55, or 2¼ times.

Fifth, furthermore, if the cooling machine were installed in accordance with these figures it would handle average summer weather conditions, but would be insufficient for extreme hot weather, the most important condition to be met by refrigeration. It is necessary, therefore, to further increase the size of the machine in the ratio of the difference between the maximum summer temperature and 35° and the average summer temperature and 35°.

Sixth, one further allowance should be considered, namely, the fact that in many cases, for one reason or another, it is either impossible or undesirable to operate the machine except during certain parts of the day. The machine size must, therefore, be increased by as much as may be required to produce the desired amount of refrigeration in the short time available.

Seventh and finally, if the machine is not placed directly beside the box to be cooled, allowance must be made for the heat inflow into the insulated cold main. The amount of heat entering from this source is often of considerable importance, particularly with small machines.

When one comes to apply these figures to an individual case the size of machine is apt to work out so large as to be rather startling. There are so many elements that are entirely uncertain, such as the kind of workmanship in the insulation, the amount of leakage through doors, the kind of care the refrigerator will be given, the probability of the doors being left more or less ajar; there are, in fact, such a multitude of very uncertain elements that considerable leeway ought to be allowed in the size of machine.

Where the amount of refrigeration is large, as in a good sized storage ware-

house, one can always throw a large part of the machine capacity to any given box where special need exists. To do this with a small machine would almost certainly rob some other box, if indeed there happened to be another box to rob. One cannot emphasize too strongly, therefore, the importance of having ample capacity in small refrigerating machines.

In installing cooling surface in refrigerators it is often necessary to arrange the layout as one can rather than as one would like to do it.

If efficiency in the use of the cooling surface is the only consideration a lower temperature can be secured in the refrigerator by placing the coils directly on the ceiling than in any other way. An arrangement of this kind, of course, is sure to keep the box rather moist and, except in rare instances, is not permissible.

In a great many cases the only thing that can be done is to place the cooling surface directly on the walls of the box. There are, with this arrangement, several disadvantages. In the first place, goods stored on shelves close to the coils are apt to be pushed against them, and constant care is essential, and unfortunately rarely given, to keep the coils clean. Goods placed near the coils are also colder by far than goods toward the middle of the refrigerator. There is no direction given to the circulation of the air—that is to say, there is apt to be considerable eddying between the rising and the falling currents of air so that the circulation is often rather sluggish.

There is often considerable trouble from deposit of moisture on the walls of the box in this arrangement. When the box stands closed for a considerable period the walls and ceiling become quite cold by direct radiation to the coils. When the door of the refrigerator is open the cold air in the box rushes out, and warm air, often heavily laden with moisture, comes in. This warm air strikes the surfaces and immediately deposits moisture, often to so great an extent as to cause serious dripping from the ceiling on to the stored goods. Frosting on the walls is of course caused in the same way, but is not so serious on account of the element of dripping on to goods being absent.

This deposit of moisture on the ceiling of the refrigerator is especially apt to occur at a point farthest from the cooling surface on the walls. This is due, undoubtedly, to the sluggish motion of the air in this part of the refrigerator, the circulation being considerably better nearer the coils. The air which has been more or less dried by the deposit of moisture on the cooling surface gradually dries the surfaces with which it comes in contact as it circulates.

The best arrangement of cooling surface in the refrigerator is either to place it in a loft above the box, *i. e.*, above the storage compartment, or in a space alongside of this compartment, with ample air passages to permit the circulation of the air between the two compartments. This arrangement is, of course, inefficient as regards the use of the cooling surface, but gives a very much more satisfactory refrigerator. Moisture is deposited on the coils, the air passes back to the refrigerator partially dried, and, if the box is properly proportioned, the air in passing over surfaces of the refrigerator, as well as over the goods, dries them and keeps them in good shape.

Comparatively few refrigerator builders have any realization of the vital importance of having large air passages, or, if the builders of ordinary household refrigerators have this appreciation, they use it to the disadvantage rather than the advantage of their design so far as its use to the purchaser is concerned. As already pointed out, if the air passages in a refrigerator are choked down, there will be little circulation of the air, and the refrigerator will therefore be economical of ice. It will be a refrigerator, however, in name only.

The force that causes the circulation of air in a refrigerator is extremely minute, being only the difference of weight between the air in the coil compartment and that in the same height of the food storage compartment. If there is a difference of even, say, 15° in the temperature between the two compartments the excess weight in the one over the other is obviously extremely slight.

The writer had an opportunity several years ago to make an experiment on refrigerator temperatures that brings out this point very clearly. Plate 77 shows a section through the refrigerator which was about 8 feet wide and 6 feet high. The cooling surface was located in the middle of the refrigerator with a baffle plate on each side of it, and the passages for the air were identically the same on both sides, except that the space leading from the storage compartment to the coil surface at the left was 3 inches and that at the right was 4 inches. This difference of 1 inch in this one dimension made a difference in the temperatures observed at the points marked *A* and *B* of one degree, throughout a week test.

When one considers that the average household refrigerator has air passages from 1 to 2 inches (rarely more than this) in depth, and when the average large refrigerator has only 3 or 4 inch passages, in a very great many cases, the desirability of further attention to this element in the design of refrigerators is apparent.

DESCRIPTION OF REFRIGERATING MACHINES.

The writer will not attempt any elaborate description of the various types of refrigerating machines that are used in marine work. As a matter of fact, practically every type of machine that is built has been given more or less trial in this service. He will only attempt to call attention to a few of the considerations that seem important in determining the type of machine suitable for any given installation.

For a number of years the only refrigerating machine that seemed entirely safe for use on board ship was the air machine, especially as embodied in the Allen Dense Air Machine. The skill required in the operation of these machines and their enormously high cost of operation was more than counterbalanced by the freedom from danger from escaping gases that they gave. There was no need to carry a supply of flasks containing gases at high pressure; there was, therefore, freedom from any danger to the ship from the presence of these gases, and there was no danger that the machine would be shut down from lack of chemicals. There was, of course, considerable danger of derangement of the machine in case it was not skillfully handled, and, as already suggested, the cost of operation was so high that, except for

relatively small sizes of machines, the use of this design of machine was prohibitively expensive.

In cases where the escape of gases would not be serious and where, on the other hand, cost of operation would be an important item, and where large quantities of refrigeration were required—especially in cases where a separate engine-room could be provided for the machine—the ammonia and carbonic-acid type of machine has been the ruling type. In merchant service there are a number of these machines placed directly in the main engine-room. It is unnecessary to dwell upon the matter of locating the machine in this way to the engineer who has been through the experience of an accident or the unexpected escape of gases. For the engineer who has not been through an experience of this kind, discussing the subject will not carry great weight. Human nature seems very much to prefer the process of locking the stable after the horse has been stolen.

As has already been indicated, the ammonia or the carbonic-acid type of machine is undoubtedly the best type of machine for cases where the capacity required is considerable and where a separate engine-room can be provided. In the choice of machines for this service there is a selection to be made between the open type of machine in which the stuffing box is arranged on the piston rod, and the enclosed crank-case type. In larger units the open type of machine is, of course, almost invariably used. In the writer's judgment this type of machine is distinctly better for the small as well as for the larger work. The open-type machine has the advantage in the matter of taking up wear and constantly and readily keeping the machine in its best state of efficiency. It has the further advantage of not wearing nearly as rapidly as does the enclosed crank-case design.

Consider first the matter of the stuffing box. Where this is on the piston rod, and especially where the stuffing box is fitted with springs and with an oil lantern connecting to the low-pressure side of the machine, it is possible to run with a stuffing box so loose that the outer gland moves back and forth against the springs with each stroke of the piston and yet with no odor of ammonia discernible. The wear on the piston rod in this case is relatively small.

Compare with this the wear on the stuffing box on the shaft of an enclosed crank-case machine. The wear on this shaft is concentrated at one particular point. The stuffing box is ordinarily not difficult to keep tight or approximately tight, but when it comes to replacement the piston rod of the open-type machine is a very much less expensive part to replace and one very much more easily replaced than is the crank-shaft of the enclosed-type machine.

The capacity of a refrigerating machine, of course, falls off with increase in the clearance in the cylinder. A moment's consideration will show very clearly the simplicity of adjusting clearance in the open type of compressor and the very serious difficulty in making the corresponding adjustment in the enclosed-type machine.

Turning now to the Audiffren-Singrun Refrigerating Machine, in this type of machine the problem of a stuffing box is met by closing all of the working parts of the machine within a hermetically sealed drum. Referring to the sectional view of

the machine, shown in Plate 78, the machine consists of a shaft with a pulley at one end, a drum at the other end, and a second drum at the middle of the shaft. The machine is carried in two bearings, one on either side of the central drum, and revolves with the central drum in contact with flowing water.

The compressor, which is reduced to its simplest element because of its peculiar situation, hangs loose on the shaft inside the condenser drum and is held in position by means of a counterweight.

The dumbbell is sent out from the factory completely charged and ready to operate. The air is entirely exhausted and a charge of sulphur dioxide and a pure neutral oil is admitted, after which the machine is hermetically sealed. The working parts are thus constantly lubricated, and the pressure in the condenser is constantly forcing oil between the working surfaces of the compressors.

Oxidation of the lubricating oil cannot occur as there is no oxygen present. It is impossible to draw air into the machine because the dumbbell is hermetically sealed. No dust can get access to the working parts, and, as a consequence, the wear on these machines is reduced to a minimum.

The scheme of operation of the machine is undoubtedly entirely clear from an inspection of the drawing, except that the devices that are provided in the cold end of the machine for the return of lubricant from this end of the machine to the condenser end, are not shown, nor the means for keeping the inner surfaces of the cold end of the machine thoroughly wet with the refrigerant.

It is obvious that in a machine of this type the gas enters the compressors in practically a saturated condition. In consequence of this the compressors always operate automatically at maximum capacity, and there is no superheating of the gas with consequent loss in capacity.

Plate 79 shows in diagrammatic form the ordinary method of arranging the Audiffren-Singrun Refrigerating Machine on shipboard and an assembly in more or less detail of the machine and brine and condenser tanks as ordinarily built for this service.

The brine returning to the machine from the cooling surfaces in the refrigerator overflows from the inner tank to the outer or surge space, whence it is drawn by the pump and again circulated through the cooling surfaces. The arrangement of inner and outer tank avoids the possibility of spilling of brine with the motion of the ship. A similar arrangement is provided for avoiding any spilling of condensing water in the condenser tank.

Where ice is required in addition to cooling refrigerators, either one of two arrangements has been used—either that shown in the diagrammatic sketch or an arrangement with closed coils through which the brine circulates with an auxiliary bath of brine in which the ice moulds are placed as shown in Plate 80. This latter arrangement of ice-making must, of course, be used in those cases where the ice-making tanks cannot be placed high enough to insure flow of the brine back to the evaporator or brine-cooling tank. It has the disadvantage, of course, that the brine has to be circulated at a lower temperature than in the case of the open system.

With this refrigerating machine it is possible to place the machine close to the refrigerator on account of the simplicity of its operation and the very small amount of care that is necessary, since there is no necessity for watching expansion valves or stuffing boxes, or anything of that kind. This, of course, means a considerable saving in heat losses through the piping, which losses are, in the case of small work, such as refrigerating work on board ship ordinarily is, quite important.

In Plate 81 is shown an assembly of the Audiffren-Singrun machine on a refrigerator of the type used on torpedo-boat destroyers. The compactness of this layout, together with the avoidance of any losses through brine lines, the avoidance of the use of a brine pump with its consequent power loss, gives a very simple and economical installation.

The condenser tank in this installation is practically identical with the usual tank for standard marine work. The brine tank, however, is provided with a labyrinth where the shaft of the machine enters the tank, to prevent spilling of brine.

The circulation of the brine through the coils in the refrigerator is secured by the action of the machine itself, which throws the brine into the hood or scoop whence the brine flows by gravity.

The design of the refrigerator has also been carefully worked out, so that in storing goods in the box it is very difficult, if not impossible, to entirely block the air passages. Space is also provided so that cooling coils for drinking water may be placed directly below the brine coils, and in a number of instances this space has been so utilized.

In practical service the machine has to run, when the boat is in the tropics, about eight to nine hours a day, the run being divided partly in the morning and partly in the late afternoon.

DISCUSSION.

The Chairman:—Gentlemen, you have heard this paper on "Refrigeration and Refrigerator Insulation on Board Ship." Mr. Massa has given us a brief digest of the paper, bringing out the salient features, so as to emphasize them and suggest heads for discussion, which is an excellent thing for authors to do. The paper is now before you for discussion. There must be among our membership many people who are interested in this subject of refrigeration and who may desire to discuss this paper.

Mr. Llewellyn Williams, *Member:*—There are some statements in the paper I would like to discuss. On page 150 the author states that sheet cork is perhaps the best insulating material for use on board ship, and in the same paragraph, as I understand it, suggests that that material cannot be used for ice tanks on account of the roughness of the plates. Where a vessel is to be insulated about the ships frames, side plates, overhead beams and

deck plates, it is very difficult to do the work with sheet cork. It would be difficult to find a rougher place, or a place where it would be more impossible to fit sheet cork, than in such places; it is, commercially, impossible to make tight joints with the sheet cork between the frames and about all the rivets and landings of plates, and particularly about fore-and-aft stringers. This is a class of construction to which sheet cork does not lend itself as an insulator. I have had considerable experience in connection with this problem of refrigeration and insulation in vessels, and have found that a material which can be packed in behind boarding gives probabilities of the best results, such as granulated cork, mineral wool, cowhair, etc. Tests show that 4 inches of sheet cork and 7 inches of granulated cork have about the same heat-resisting effect, and assuming 8 inches for the granulated cork (penalizing the granulated cork), we would have a cubic foot of granulated cork equal in heat-insulating effect to half a cubic foot of sheet cork. The sheet cork costs some 54 cents against the granulated cork's 16 cents. This seems to indicate that in large installations, at any rate, the sheet cork is prohibitive. That has been my experience.

On page 154 the author suggests there is a possibility of provisions or other goods being stored directly against pipes. It is customary to put wooden battens over the face of and clear of the pipes, to keep the meat and provisions from touching the pipes. On large vessels only the overhead pipes are left exposed. All side piping has to be protected, and the bulkheads, where there are no pipes, have battens, to allow ventilation behind them. We have no difficulty in maintaining even temperature throughout ships carrying frozen meat—there is a difference of less than one degree in the various parts of the ship which are refrigerated. In chilled-meat cargoes, we maintain temperatures to within half a degree, and only have coils on the sides and overhead.

As to the question of leaking of air into the room, when the door is open, the air striking on the walls and ceilings, that will occur if air locks are not provided; and where the rooms are of sufficiently large capacity to enable the use of air locks or a small entrance chamber it should be done, obviously.

On page 156, first paragraph, the author states:—"In cases where the escape of gases would not be serious and where, on the other hand, cost of operation would be an important item, and where large quantities of refrigeration were required—especially in cases where a separate engine-room could be provided for the machine—the ammonia and carbonic acid type of machine has been the ruling type. In merchant service there are a number of these machines placed directly in the engine-room. It is unnecessary to dwell on the importance of locating the machine in this way to the engineer who has been through the experience of an accident or the unexpected escape of gases."

It does not seem reasonable to class carbonic acid and ammonia together in this connection. One is a poisonous gas and the other is not. Unless the carbonic acid escapes in such enormous quantities with very poor ventilation so that it cannot get away, it will do no harm. Carbonic acid is safe to all intents and practical purposes for use with machines placed in the main engine-room.

I would not recommend an ammonia machine, except in the smallest sizes, to be placed on the lower platform. The machines of even the small sizes are usually placed on the top sides. The smallest ammonia machines (1 ton capacity) so placed rarely contain more than 30 pounds of gas, and leakages that occur are not serious at all.

On page 156, end of third paragraph, the author refers to the wear on piston rods and

stuffing boxes. I have inquired of large manufacturers, and one firm with an output of 6,500 machines to date, 3,000 with piston rod and 3,500 with crank-shaft packings, states that in the case of piston rods they do not use the type of floating packing the author recommends. These 3,000 machines are working perfectly satisfactory, without any undue wear on the piston rods, and have the lantern oil space put up in the usual manner of the 3,500 machines with a crank-shaft packing; and in 4,000 similar machines manufactured by another firm (in all 7,500 crank-shaft packed machines) there was not one that ever had a crank-shaft replaced due to the wear of the packing. Furthermore, leakage would be across the lines of wear with the crank-shaft packing, and along the lines of wear with the reciprocating rod packing, making it much easier to pack tight a worn crank-shaft than a worn piston rod.

Referring to the dumb-bell type of machine, of the all-enclosed type, I would ask the author if they have experienced any necessity for renewing the old oil? The oil, as I understand it, is locked up in the machine with the refrigerating fluid. It would appear to me that the oil would lose its lubricating properties in the course of time through continuous friction and wearing down of the bearings, and that the resulting grit would get into the oil, unless there is some means of filtering it in circulation. Furthermore, to recommend a machine of the Audiffren-Singrun type on a vessel, where you have skilled engineers, is to expect the owners to rely entirely on the satisfactory performance of the machine as delivered to them by the makers, with the knowledge that their engineers are absolutely unable to help themselves in the event of trouble. This does not seem to me to be a good proposition in a case where you must have skilled mechanics on hand at all times. If it were possible to open the machine and effect repairs in the event of trouble, things would be different; but as I understand the situation, if the machine gives trouble it must in its entirety be removed from the vessel, sent back to the manufacturers, repaired and charged, and returned again to the vessel. In my opinion that means it would be necessary, on ocean-going vessels, to carry two complete units, either one of which is capable of performing the full cooling duty. That seems to be a prohibitive proposition, and much more serious than carrying a spare flask of ammonia or a couple of flasks of carbonic acid gas, which can be obtained in practically any civilized port in the world.

The Chairman:—Is there any further discussion? If not, I will call on Mr. Massa to close the discussion.

Mr. Massa:—In regard to putting the insulation on the side plates of the ship, I did not refer to that particular location. I had in mind the small refrigerators cooled by small machines. However, as a matter of fact, I have seen, on several submarines, sheet cork put on the shell of the ship, and apparently put on in perfect condition. While I am not a marine man, it would seem to me that would be quite as difficult a place to put the cork as any other place on the ship.

As to a comparison between the sheet cork and the granulated cork, we, of course, realize that the granulated cork is, we will say, half as good as the sheet cork. When you come to deal with small refrigerators, such as I had in mind in this paper, the addition of 4 inches of thickness on all the surface means an astonishing percentage of volume you are taking up, and in ship work, unless I am very much mistaken, space is at a premium. If Mr. Williams will compare the cost of a cubic foot of storage space on board ship,

especially under present conditions, against the saving by using granulated cork, he will find the balance in favor of the more compact insulating material.

When it comes to a location where space is not so important, nor durability, the granulated cork is not only all right but is the thing to use. When you get down into the southwest, where they have all kinds of space, you can often use cotton seed hulls which are cheaper yet, and satisfactory, *i. e.*, where you have space to put 24 inches of insulation on the sides of a brine tank.

As to the proper location of the door passing into the refrigerator, that is a thing which should be given careful consideration, but it is not always done, and it is to point out the difficulty there that I have made the note on the subject which I did. Air locks are, of course, the things to use where you have a large box. Frequently, in the smaller refrigerators, there is no space on board ship to do it. I remember one case where we had good luck and there was space for an air lock. Very frequently, however, there is not space for it, and you have to do the best you can with the conditions to be faced.

I am sorry that I spoke of carbonic acid and ammonia in the same sentence. I might have had a period between the two. Carbonic acid is a less difficult gas to deal with. I do not know that it is worth while going into the difference between the two substances.

As to the ammonia leakage, we have two companies under the same financial management, where the chief engineer of the one company had an experience with ammonia in the engine-room, and we cannot get even our machine in his engine-room. The other man has never had such experience, and we cannot get our machine into his engine-room for another reason. He is absolutely not afraid of ammonia. The man who has had the experience is afraid of it.

As to the difference between the open and enclosed types of machine, I have some photographs of crank shafts that have come out of enclosed-type machines, and they do show very decided wear. It would seem, further, that the statement of a company that has built some seven thousand enclosed-type machines and "never had any trouble with them" is not very serious criticism. I do not feel like arguing the point. I think on the face of it that the wear is more uniform and more readily taken care of on the piston-rod than on the crankshaft type of stuffing box. As I said in the paper, I know of one line of machines, with which I am not connected in any way, where they do use a flexible stuffing box, and the friction certainly is very much decreased on these outfits. These machines are used on small work where temperatures change rapidly and where the box without this adjustment automatically cannot be made to stand up without constant care.

As to the oil in the hermetically sealed type of machine, that oil is never replaced. Mr. Williams is laboring under the very common impression that an oil in some way breaks down, as if there were some actual structural change in the oil. We often speak of oil wearing out. There are only two things that happen to oil, when you analyze the matter—one is that it oxidizes, and the other is that it gets dirty. The oil in the hermetically sealed type of machine is not exposed to the air; it cannot be exposed, and neither can it get any dirt in it. The machines are cleaned with a degree of care that is almost unbelievable. Until I had an opportunity of seeing how it was done, I had no idea of their being handled in any such careful way as they are handled. They are absolutely clean—surgically clean—and the proof of experience is that that type of machine does stand up. We have had machines in this country for about six years now, running right along and giving satisfactory service—at least such service that we have never heard any complaint at all—and I remem-

ber seeing one machine, which had been taken apart after nine months of service, twelve hours a day, and the oil was perfectly good and put back into the machine when the machine was put together again.

As to the helplessness of an engineer with a hermetically sealed machine, we were much afraid of that at first—I know our customers were, and the question was up repeatedly. As a matter of fact, we started with spares in the first marine installation we made—we had a spare machine in that installation—and we have never since then put on a spare machine.

Mr. R. C. Carpenter (Communicated):—Although not a member of your honored Society, I am greatly interested in the statements made by Mr. Massa as to the method of applying cork insulation for the cold storage rooms of vessels, which is similar to that employed in the application of cork insulation in modern cold storage buildings.

What he states regarding the difficulties with cork is of great interest and points out the need for a good insulating material which has structural qualities.

I have recently made an investigation, rather scientific in its character, respecting the heat-insulating properties of cork and an extremely light wood having considerable structural strength, which grows in the tropical regions of North and South America and which is known popularly as balsa wood or scientifically as *Ochroma lagopus*.

I prepared a paper for the American Society of Civil Engineers on the properties of balsa wood, which appeared in the proceedings of that Society of May, 1916. In that paper I gave results of actual tests of strength and also of heat transmission when employed for the purposes of insulation.

Balsa wood I believe to be peculiarly suited for insulating the cold-storage rooms of a vessel, as it can be worked with the same facility as many of our modern woods. It has a high insulating value and will in practice, I believe, be found superior to cork. It can easily be applied, and, so far as I can ascertain, is not objectionable from any source whatsoever when it has been properly treated. If the wood is used in its natural state, it is likely to have a very short life, but when treated by the Marr process, its life is indefinitely prolonged and its qualities are improved in various other respects.

Capt. A. P. Lundin, a member of this Society, has had considerable experience with the use of balsa wood for insulation on shipboard, and with excellent results. There is no difficulty of the character mentioned by Mr. Massa as applying to cork, and the insulating qualities are superior. The life of the structure is all that can be desired; consequently it is only reasonable to expect that, when this material becomes better known, it will be in great demand for insulating purposes.

I investigated the heat transmission through both balsa and cork and present here a brief statement of the results which I obtained.

The heat transmission can be expressed by the following formula:—

$$\frac{1}{k} = \frac{1}{a_1} + \frac{1}{a_0} + \frac{x}{e}$$

The symbols used are as follows:—

e = "Specific conductivity," or heat transmitted per degree of difference of temperature of the sides of the material, per unit of time, per inch of thickness.

x = Thickness.
a_1 = Coefficient of surface flow entering the body.
a_0 = Coefficient of surface flow leaving the body.
k = Coefficient of total heat transmission per degree of difference of air temperature, per inch of thickness.

For the balsa wood, the value of e, as determined by the Bureau of Standards, was equal to 0.35, expressed in English units and Fahrenheit degrees.

The value of cork varies with the quality of the cork from 0.32 to 0.42. In practical application of cork, cracks or openings are likely to occur and these are usually filled with cement. The heat transmission through cement is known to be high, and as a result the cork insulation is, in practical application, likely to be less efficient than the balsa wood, which can be readily put up in such a way as to avoid air spaces.

The formula, as stated above, applies to a wall of a single thickness; in the case of a wall made up of two different materials with an air space between, then it is obvious the formula would become as follows:—

$$\frac{1}{k} = \frac{1}{a_1} + \frac{x}{e} + \frac{1}{a_0} + \frac{1}{a_1'} + \frac{x}{e'} + \frac{1}{a_0'}$$

It is evident that the quantity of heat transmitted through any body is equal to that passing in succession each heat-resisting part. For example, if heat passes through a simple homogeneous body from a higher to a lower temperature, and from the air on one side to that on the other side, it must overcome (1) the resistance of the entering surface, (2) the resistance of the material composing the body, and (3) the resistance of the surface from which it emerges. The surface resistances, (1) and (3), are overcome by radiation and convection, the interior resistance, (2), by conduction.

The surface transmission coefficients have been worked out carefully for numerous cases by Rietschel and other German engineers. These are given by Kinealy, in English units, as follows:—

$$a = c + d + \frac{(40c + 30d)t}{1000} = c(1 + 0.004t) + d(1 + 0.003t)$$

$c = 0.82$ for still air.
$c = 1.03$ for air with moderate velocity.
$c = 1.23$ for air with high velocity.

VALUES OF d.
(Per degree diff. of temperature Fah. per hour)

Brickwork	0.74	Iron, rusted	0.69
Mortar	0.74	Cast iron, new	0.65
Plaster of Paris	0.74	Sheet iron, polished	0.009
Stone masonry	0.74	Brass, polished	0.053
Wood	0.74	Copper, polished	0.033
Paper	0.78	Tin, polished	0.045
Glass, dry	0.60	Zinc, polished	0.049
Glass, wet surface	1.09	Zinc, dull	0.10

For thick walls and poor conductors, t is so small that it can be neglected. Rietschel gives values of t, for windows, as 36; for brickwork 5 inches thick, as 14; for brickwork 30 inches thick, as 5; for wooden doors, as 2.

The following table expresses the amount of heat transmitted, expressed in English units, for different thicknesses, and is in such close accordance with results obtained in practice, that it can be used as a basis of calculation for design of insulating materials of either balsa wood or cork of the highest quality.

"Specific conductivity"	Thickness in inches	"Coefficient of heat transmission" B. T. U.
$e=0.35$	$x=1$	$k=0.242$ per hour
$e=0.35$	$x=2$	$k=0.143$ per hour
$e=0.35$	$x=3$	$k=0.1015$ per hour

Mr. A. P. Lundin, *Member* (Communicated):—The writer's attention was drawn to balsa wood many years ago, during voyages to tropical countries, viz., Central and South America, Central Africa, and also India, in all of which the same species can be found; and he first remarked it when a number of natives came floating down a river on a raft made up of balsa logs. The logs were covered more or less with bark, and where this was chipped away the hard surface still remained, which is found on the outside of balsa logs, under the bark; the ends were covered with tar, or some waxy substance.

The natives, particularly in Central and South America, use such rafts to float their products to the sea coast, and seldom use them more than once; for one reason, because it would be difficult to bring the rafts up against the stream, and because the wood absorbs water very readily and the raft is more or less water-logged after arriving. Of course, in solid logs, with the ends closed up, the absorption is not so rapid as when balsa is cut up in planks and freed from bark.

Later, when engaged in the life-saving equipment business, it was brought to the writer's attention that some crude attempts had been ma le to use balsa in life-preservers. On taking over a boat shop in Long Island City, a quantity of balsa was found there, and, on inquiry as to its purpose, it was learned that experiments had been made with it in life-belt manufacture, but that the wood absorbed water so rapidly that the belts had to be made two or three times as large as the ordinary cork life-belt to assure the required buoyancy. Subsequently, chemical experts were put to work to devise methods for making the wood non-absorbent.

First, painting was tried, but, owing to the peculiar nature of the material, the paint was rapidly absorbed, and coating it over and over meant having just as much paint as wood, which added greatly to the weight. Then varnishing was tried, but, owing to the moisture left inside, the varnish cracked and blistered off.

Next, several mixtures of paraffin, asphaltum, gilsonite, etc., were tried, which gave a fairly good outside coating, penetrating about ¼ inch on the ends and about $\frac{1}{16}$ inch on the sides, and the problem was apparently solved. However, before long it became evident that, owing to the cellular structure of balsa, which i mostly pith, and the great quantity of moisture sealed up in the wood by the impervious surface treatment, dry-rot developed even sooner than in the untreated balsa.

Just at the time these difficulties became apparent, Colonel Marr's water-proofing process was brought to the writer's attention, and after numerous experiments with the new method it was successfully and practically applied.

The United States Government has tried out balsa life-preservers, life-buoys, etc., as compared with the cork articles, for a period of forty-nine days (twenty-four hours per day), at the end of which period the cork preserver had lost all its buoyancy and the balsa preserver still retained the buoyancy stipulated in the government requirements.

A few years ago, while working on the buoyant-material proposition, it was considered that, as balsa, owing to its peculiar structure, was so advantageous for use in buoyancy products, it might also be adaptable for insulation purposes, and accordingly experiments in that direction were begun. The first ice-box made of the new material was on the writer's motor boat, and the results were surprising. All during the hot summer weather, ice was put in the box on Friday or Saturday, and on the following Friday or Saturday the temperature in the box would still be quite low and some ice still left in the box.

Naturally, all first work in the line of balsa insulation was more or less crude, and the importance of scientific investigation was soon realized.

It was particularly fortunate that Professor Carpenter became interested in this material. The writer well remembers that when he first spoke to him about this wood, and stated that it was all pith and no fiber, he and the gentlemen in his company looked very skeptical. However, he was sufficiently interested to visit the Welin plant, intending to remain there half an hour, but he spent practically a whole day, and when last seen on that occasion he had all his pockets full of balsa, and he has been steadily devoted to the investigation ever since.

The writer does not pretend to be an expert on insulation or non-conductivity, but looks at this material from a practical rather than a scientific viewpoint.

The principal feature in insulation material is, of course, that it must be a good non-conductor, but no doubt in the future engineers will also consider structural strength, and the possibility of making up complete homogeneous units will also be considered in judging the efficiency and value of insulating material, particularly where it is to be used in making ice-boxes and as insulation for buildings, in ships, and in railroad cars.

The principal consideration is a commercial one; in other words, good engineers always try to obtain the highest total efficiency, and commercial men want it and are willing to pay for it.

In shipping, for instance, it is known that almost any ship can be insured if built to certain requirements, such as Lloyds, and it can be insured at the lowest rates, except, of course, in time of war. All cargo on such ships can also be insured at reasonable rates, except one class, and that is perishable food-stuffs carried in refrigerator compartments, which are always carried at the shipper's or consignee's risk. Neither the steamship companies nor the insurance organizations will place insurance on such goods, except in the event of total disaster to the ship. Why? Not because the science of refrigeration has not kept pace with the science of naval architecture, but because of the fact that if a break-down occurs in the refrigerating machinery, the cargo will spoil, as the insulation is not reliable enough to keep the temperature sufficiently low until the machinery can be repaired and the system put to work again.

The writer had an experience of this kind, many years ago, when on board a meat ship running from Australia to London. The machinery broke down while running through the Red Sea, and more than half the cargo spoiled in less than twenty-four hours.

A few years ago, in a meat market in Seattle, a new refrigerating plant, which had what might be called ordinary commercial insulating material, broke down, and before new parts could be obtained to replace the broken ones, and the machinery put in working order again, the damage to the meat in the market amounted to more than the cost of the refrigerating plant.

Therefore, when it comes to efficiency in insulation, there is still room for improvement. Perfection cannot be attained, but balsa wood will surely help to make insulation perfect, as it is not only a very efficient non-conductor, but has sufficient structural strength, and, through its physical properties, permits of constructing units with practically unbroken insulated surface walls.

A small ice-box, or pony refrigerator, made by the Welin Company, is of balsa wood, 2 inches thick, about 36 inches long, 21 inches wide, and 22 inches deep, and weighs about 30 pounds. Such a box could not be made up of any other known insulating material. It is strong enough to stand severe jars, and a man could jump on it without straining it unduly. Of course, other woods will stand more rough usage than balsa, but, to meet this factor of additional strength, particularly on the surface, paneling made from the bark and waste of the wood is applied to the outside.

A small container, on the order of a thermos bottle, but in the form of a box made of 1-inch material, has a capacity of about 1 cubic foot and weighs 6 pounds. When going on an automobile trip or something of that sort, the "lunch" can be placed in such a container—whether it is to be kept hot or cold. If it is wanted cold, a little ice should be put in to keep it so.

Butter has been sent all the way from Virginia to Southern California in such boxes, at an average outside temperature of 82°, and the trip took eight days by the slowest route. Yet, when the boxes arrived at Los Angeles, the butter was still hard and frozen.

Even if balsa had 30 per cent less efficiency as a non-conductor, the writer believes that it would meet a very common requirement for insulation, not satisfied by another material lacking in structural strength, which makes it possible to eliminate all leakage of heat through imperfect joints, or by use of cement or nails which may be classified as good conductors. Other insulating materials are almost entirely limited to use as a lining for a structure built of good conducting materials.

There are a thousand and one uses for balsa, and in the future new ones will continually develop. Thanks and grateful acknowledgment are due to Professor Carpenter for the earnest scientific work he has done in investigating this wood.

Mr. Massa (Communicated):—Referring to Professor Carpenter's remarks and the samples of balsa wood, this will undoubtedly be an interesting material to experiment with further in actual installations and to observe the results as to its durability.

I note no mention is made of the matter of fire resistance, and I understand that the balsa wood is not fire-proof.

As to fitting the balsa wood in place it is not clear to the writer as to why it should be any easier to fit than is cork.

As to the matter of cracks and joints in cork work being filled with cement, the instructions to workmen on this point are uniformly to exercise the greatest care to avoid any cement in the joint, and the writer has never happened to see a case where these instructions were not followed. It may be, however, that this defect occasionally does occur.

Further, with reference to the ease of fitting cork in ship-work, an installation was made

recently of pure sheet cork on supply ship No. 1, the Bridge. The success of the work was largely a matter of proper design. I am sorry that this installation did not occur to me in my oral discussion in reply to Mr. Williams' remarks.

I want to take this opportunity to add the following notes with regard to Mr. Williams' comments on my paper.

First, as to ice-tanks and the undesirability of sheet cork as an insulating material attached directly to the tanks, I am sorry to note that I omitted in my paper one of the principal reasons for avoiding this construction. Not only are ice-tanks, as ordinarily constructed, very rough work as compared with the shell of the ship, but the metal is subjected to a very wide range of temperatures, and if the cork is cemented directly to the metal the different coefficients of expansion of cork and metal will cause the cork to separate from the tank and leave a space in which moisture will accumulate. This same difficulty would undoubtedly occur in case cork is cemented directly to the skin of a ship in insulating large compartments. In the case of submarines, on the other hand, the range of temperatures to which the ship is subjected is much smaller, so that this difficulty does not appear.

With regard to the maintenance of uniform temperatures in refrigerators with wall coils, Mr. Williams' comment is based on his experience with large compartments and goods that are held in them for relatively long periods and at steady temperatures. This limitation should have been noted in his remarks. My notes, as already stated, refer to small compartments that are subject to rapidly varying conditions, and my statements regarding the effect of this coil arrangement are based on actual installations.

Coming back again to the question of balsa wood, I have the following quotation to submit from a letter by Mr. J. H. Stone:—

"Taking up Captain Lundin's remarks first, he states that the balsa wood is mainly a sort of pith with a great affinity for water and he states that all the usual methods of waterproofing failed. Finally, according to his statement, a process which he does not describe but calls the Marr waterproofing process, proved satisfactory, rendering the wood non-absorbable. Before being able to comment on this method it would be necessary to know of what it consists, but it is evident that it has not been tried under severe practical conditions for any considerable number of years, and until that has been done it is impossible for anyone to be sure that it will be durable. Its cost must also be taken into consideration.

"I do not find a word as to the most important question of all, viz., its fire-resisting value. I take it for granted, because of the absence of any reference to this point, that as yet no satisfactory means has been found of fire-proofing the balsa wood. In these days any insulating material, no matter how efficient, must be either fire-proof or very slow burning to be favorably considered by practical men, and this is most important in the insulation of vessels.

"There was in England some years ago an uneasy feeling that various refrigerated ships that were lost with all on board—none knew how—might have come to their end through spontaneous combustion taking place in their powdered charcoal insulation, and the London Board of Trade had experiments made and held an exhaustive inquiry. As I recall it, this inquiry resulted in a Scotch verdict "Not Proven," but charcoal has from that time on been gradually abandoned by British shipowners. They have taken to mineral wool which they call silicate cotton, and later to cork, using both granulated and sheet cork. I am certain that unless this material can come to them and to American shipowners as well,

with clear record that it is slow burning and will be a defense to a ship rather than an added hazard if she should have a fire in her holds, it will be impossible to introduce it widely.

"There is one statement in Captain Lundin's paper regarding the buoyancy of cork as compared with balsa wood that is undoubtedly a misprint, since it is an absolute misstatement of facts. The statement is, that at the end of forty-nine days "the cork had lost its buoyancy." The natural structure of cork is such that it will not lose its entire natural buoyancy in forty-nine years, to say nothing of forty-nine days.

"Referring now to Professor Carpenter's remarks, I note his statement that the heat transmission of balsa wood is .35 British thermal unit per degree Fahrenheit. This I take to be per degree Fahrenheit per hour, giving a heat transmission per 24 hours of 8.4 British thermal units, which is about the same as lith.

"I have not seen the report of the Bureau of Standards, but I understood recently that they gave pure sheet cork a heat transmission of 7.4 British thermal units. This would be .309 British thermal unit per hour, which is less than Professor Carpenter states in his remarks.

"Captain Lundin intimates that the balsa wood will cost as much as pure cork sheets to install. Professor Carpenter's remarks indicate that the insulating value is about 13½ per cent less efficient than an even thickness of pure cork sheets. As to the claim of less joints in the construction there is nothing to that to any practical extent, since cork can be made of any size that the trade requires within reasonable limits; *i. e.,* they can be made from 6 to 8 square feet to the board without any difficulty. Cork is now being made in Spain 36 inches by 24 inches.

"The only advantage the balsa wood may have is somewhat greater structural strength and in certain places this would be of real advantage, though, after all, such cases would be very limited in number, because it would not do to form an independent building wall; and as for partitions, we know perfectly well that pure cork board without any wood in the construction can be erected in partition form amply strong for dividing interior rooms of cold storage buildings, and I have put up such partitions 23 feet high, consisting of two courses of pure cork sheet with a cement core between and finished with one-half inch cement each side. These are giving good service to-day after being in use for the past seven or eight years. In one case that I know of, apples in barrels were piled against them 14 feet high, the barrels resting on the side so that the thrust came solidly against the cork partitions. I do not believe a wood partition would stand that strain.

"Turning now to the question of durability of the balsa wood and its liability to take up moisture after a long time in service, I want to cite the behavior of pure compressed cork sheets in this regard as showing what can be expected from that material and what balsa wood must do to equal it.

"In 1894, which you will note is over twenty-two years ago, I furnished the sheet cork insulation for the American built ocean liners St. Louis and St. Paul. Some three years ago the spruce sheathing in the St. Louis beef storage room had rotted out and had to be renewed, and when it was taken down her chief engineer reported that the cork sheets back of it were sound and bright as when they were put in the vessel twenty years before. During the last two years I have crossed the ocean three times on the St. Paul. I have talked to the chief engineer and have inspected the cold-storage rooms. He tells me that her insulation is still in first-rate shape and the rooms are holding temperatures beautifully; the only trouble they have had has been in the overhead insulation of the rooms, which in the St.

Paul consisted of mineral wool. The vessel was delayed, and in the hurry to get her into service they gave up the scheme of fitting the cork sheets around the deck beams as had been specified and instead erected a double course of spruce sheathing under the deck beams and filled the spaces between them with mineral wool. The vibration of the vessel in time reduced this mineral wool largely to powder, and it had to be removed and new insulation installed overhead. The sheet cork, however, on the walls and floors of the rooms was found to be in first-class condition, as I have said.

"When we remember that there is bound to be more or less moisture getting into every cold storage room, not only from the goods carried but from the opening of the doors and the condensation of moisture which then enters, it is clear that any insulation to be perfect must be non-absorbent, and when we take a material which is in its natural state admittedly very absorbent, and attempt to reverse its natural qualities artificially, I do not believe that the results are likely to be satisfactory in the long run. A very good job may be done in the laboratory or on a small scale, but as the business increases and it becomes necessary to trust ordinary labor to handle such processes on a large scale, then is the time when trouble begins.

"As I see it, then, we have this material possibly waterproof but probably not, almost certainly highly inflammable, since its backers do not touch upon that most important question, being according to their own figures more than 13 per cent less efficient than pure cork board at even thicknesses, and costing to install about the same price. I do not see what there is in this showing to interest a practical owner of either a vessel afloat or a cold-storage plant ashore."

The Chairman:—On behalf of the Society, I will extend the thanks of the Society to Mr. Massa for his instructive paper, which I am sure that the Society wishes me to do.

We will now take up paper No. 13, entitled "The Resistance of Various Types of Barges in Shallow and Deep Water," by Prof. H. C. Sadler, Member of Council.

Professor Sadler presented the paper.

THE RESISTANCE OF VARIOUS TYPES OF BARGES IN SHALLOW AND DEEP WATER.

By Professor Herbert C. Sadler, Member of Council.

[Read at the twenty-fourth general meeting of the Society of Naval Architects and Marine Engineers, held in New York, November 16 and 17, 1916.]

The subject matter of this paper represents a digest of the results of a number of experiments on various types of barges, originally undertaken for the "Board on Experimental Towboats,"* U. S. Army. A full report in somewhat different form was published as Document No. 857, House of Representatives, 63d Congress, 2d Session.

Unfortunately the above report is now out of print, so it was thought advisable to place the results of the above experiments in some permanent form in the volumes of our Transactions.

In the original report, the results were worked up for a particular size of vessel (150 feet long). In order to make them more readily applicable to any size, the curves have been re-plotted in terms of residuary resistance per ton of displacement on a speed-length ratio base (V in knots; L, length over all, in feet; R_w in pounds; displacement in long tons).

The wetted surface, and hence frictional resistance, in the different types varies somewhat, but may easily be calculated for any specific size. So far as relative results are concerned, the inclusion of this does not appear to affect the standing of any particular type materially.

DESCRIPTION OF MODELS.

In all, nine different forms were tried, the general designs being shown in Figs. 1 to 3, Plates 82 to 84, the bows and sterns being the same in all cases. It will be seen that they cover variations of "rake" forward and aft, shape of side, and shaped versus flat forms. The middle body in all cases was box-shaped with square corners.

No. 1.—Rake one-fourth length, rounded sides.
No. 2.—Rake one-eighth length, rounded sides.
No. 3.—Rake 45°, straight side.
No. 4.—Rake circular, straight side.
No. 5.—Rake one-fourth length, straight side.
No. 6.—Rake one-eighth length, straight side.

*Col. L. H. Beach, chairman, and Colonels Newcomer, Potter and Keller.

No. 7.—Flat-iron shape one-fourth length, vertical sides.

No. 8.—Ship-shape one-fourth length.

No. 9.—Spoon-shape one-fourth length.

The models were all tried at the same two displacements for each type, corresponding to the "load," and "light," or 55 per cent of the load displacement of No. 8, with the exception that Nos. 1 and 9 were tried at the same load draught as No. 8 on account of their relatively small displacement. There was, therefore, a variation of draught in most cases, as shown in the following table:—

TABLE I.

No.	$\frac{L}{B}$	$\frac{B}{d}$ light	$\frac{B}{d}$ load	$\frac{\Delta}{\left(\frac{L}{100}\right)^3}$ light	$\frac{\Delta}{\left(\frac{L}{100}\right)^3}$ load
1.....	4.41	7.32	4.857	136.5	223
2.....	4.41	8.5	4.857	136.5	247
3.....	4.41	9.5	5.41	136.5	247
4.....	4.41	9.86	5.6	136.5	247
5.....	4.41	7.45	4.56	136.5	247
6.....	4.41	8.72	5.1	136.5	247
7.....	4.41	8.72	4.857	136.5	247
8.....	4.41	8.5	4.857	136.5	247
9.....	4.41	7.31	4.857	136.5	223

Each model was tested in four different depths of water, or corresponding to a vessel 150 feet in length, these would be 6 feet, 9 feet, 12 feet, and "deep water." The results are shown in Figs. 4 to 7, Plates 85 to 88.

In the shallower water resistance curves tend to arrange themselves into two groups, the forms with the straight sides having, on the whole, greater resistance than those where the sides are curved.

The ship-shaped form No. 8 is uniformly good, but it is followed closely by the scow form No. 2.

Number 7 appears at its best in very shallow water, otherwise it does not seem to be as good as some of the others.

Numbers 1 and 9 (long rake) are easily driven forms, but do not have the same amount of displacement at the load draught as the others. The effect of square versus round corners may be seen by comparing these two types.

The form with the circular end (No. 3) shows up fairly well in very shallow water, as it is the one of greatest displacement and consequently floats at a lighter draught. In fact, the clearance between the bottom of the vessel and that of the river appears to have a marked effect in the resistance of any form.

Number 5, on the whole, appears to be rather a poor form.

In deep water the forms arrange themselves in somewhat the same order, the straight-sided ones having larger resistance than those with curved sides, and those with "easy" rakes less than those with the steeper rakes.

Some additional experiments were made with the same shapes of ends and sides, but with smaller beam. The resistance per ton of displacement for all practical purposes appeared to be constant, or, in other words, the resistance varied about as the beam within the limits of speed for vessels of this type.

GROUPS.

All the above forms were tried in groups of six, two abreast and three deep, and certain selected forms in groups of two, three, four, and five. In all cases the models were lashed close together, corresponding to the common practice in this country.

The results for the groups of six are shown in Figs. 6, 8 and 9, Plates 87 and 88.

It is interesting to note that some of the forms with straight sides show relatively better results when grouped together. This is probably due to the fact that they present perfectly flat sides and no spaces between, whereas those with curved sides offer places for the creation of extra wave-making resistance.

On the whole, Nos. 2, 3, 4 and 8 are fairly good. No. 7 is, however, still a rather poor form.

In groupings other than those mentioned above, some interesting facts develop, as may be seen from Fig. 10, Plate 89. The grouping is also shown on the diagram, and the curves are those for barges Nos. 2 and 8.

In deep water the resistance per ton decreases slightly as the number of barges is increased.

In shallow water, by adding one extra barge in front, either in the three or five combination, the resistance is actually decreased as compared with two or four barges. In other words, it is actually more economical to increase the load 50 per cent in the case where two barges are towed abreast.

The explanation appears to be that the extra barge acts as a "bow" to the others and reduces the wave-making resistance, both by increasing length and reducing head resistance.

In general it may be concluded that, although the ship-shaped form is perhaps the best, taking all things into consideration, a form such as No. 2, with a moderate rake and curved sides, is practically as good, and when simplicity of construction and repair are taken into account, the latter form is to be recommended.

DISCUSSION.

The Chairman:—Is there any discussion on the paper by Professor Sadler, entitled "The Resistance of Various Types of Barges in Shallow and Deep Water"? Are there

any eastern river boat men here, with practical experience, to throw any light on the subject?

THE CHAIRMAN:—We will extend the thanks of the Society to Professor Sadler for his very able paper, and pass to the next paper, No. 14, entitled "Feathering Paddle-Wheels," by Professor E. M. Bragg. In the absence of Professor Bragg, this paper will be presented by Professor Sadler.

MR. E. H. RIGG, *Member* (Communicated):—Owing to the amount of work still ahead of the meetings and the approach of the time for adjournment, I felt that it was perhaps better to submit my remarks in writing after the meetings.

One who has carefully followed commercial model tank work cannot fail to be gratified by the marked amount of progress that has been made during the last four or five years, and to no one are we more indebted than the present author for his valuable contributions to our transactions.

The present paper explores a field of which the literature is very meagre, at least, in our own language. Continental Europe has highly developed canal and river systems, but the possibilities of saving due to improved barge forms are nowhere greater than with us.

The scope of the present paper is wide and we are enabled to choose the most suitable form not only for deep water, but also for shoal water and for towing in fleets.

Our transactions bear witness to the improvements taking place in inland boats, vide Mr. Bernhard's paper last year as an example; the present paper is also of value to the floating equipment departments of our railroads.

Professor Sadler presented the paper.

FEATHERING PADDLE-WHEELS.

By Professor E. M. Bragg, Member.

[Read at the twenty-fourth general meeting of the Society of Naval Architects and Marine Engineers, held in New York, November 16 and 17, 1916.]

In the year 1913 tests were made in the model basin of the University of Michigan upon certain models of radial and feathering paddle-wheels. These tests were made for a board of army engineers appointed to investigate the question of towboats and barges for the Mississippi River. The complete report upon the subject can be found in House Document No. 857, entitled "Experimental Towboats."

Since the publication of the above report I have taken the results for feathering wheels and plotted them in a more compact form and have compared the results obtained from the model wheels with those for full-sized wheels.

While it is not the purpose of this paper to discuss radial paddle-wheels, it may not be out of place to call attention to some of the differences which exist between the two types of wheels. As shown by Fig. 1, Plate 91, the radial paddles give more thrust than the feathering for the same slip, but work at a lower efficiency. The radial wheel has its maximum efficiency at about 10 per cent slip, while the maximum efficiency of the feathering wheel occurs at about 15 per cent slip. The efficiency for both types decreases with increase of dip but the decrease is less for feathering blades than for radial blades.

In Fig. 2, Plate 91, will be found the thrusts obtained from models of feathering paddle-wheels 12½ inches in diameter with blades 2 inches wide, or with a blade-width ratio of 0.16. In Fig. 3, Plate 92, will be found the thrusts obtained from model wheels 12 inches in diameter with blades 1.5 inches wide, or with a blade-width ratio of 0.125. Fig. 4, Plate 92, shows the effect of blade-width upon thrust and efficiency. The blade-width ratios most commonly used are in the neighborhood of 0.16 and from Fig. 4 it can be seen that no great error will be made if we assume a straight line relation between the values 0.16 and 0.125. These thrust values are for fresh water, and in salt water they would be 2½ per cent larger.

The efficiencies for blade-width ratios in the neighborhood of 0.16 are given in Fig. 5, Plate 93. The efficiencies for narrower blade-widths would be somewhat higher than these values. In the computations made in this paper all blade-widths were assumed to have the efficiencies given in Fig. 5.

The quantities used in plotting these thrusts and efficiencies are slip at center of blade, eccentricity ratio, dip ratio, and pitch ratio. Fig. 6, Plate 94, shows what is meant by the above terms.

Many designers of feathering paddle-wheels give the slip at the outer edge of the blade and assume that G (see Fig. 6) has a velocity proportional to its distance

from A. As a matter of fact the feathering gear causes the blade to move through the water approximately in a vertical position rather than a radial position, and the velocities of all points in the blade are approximately the same and equal to the velocity of the trunnion C. For this reason the slip based upon the velocity of the middle of the blade is more nearly the actual average slip of the entire blade and is the one used in this paper.

If the slip S_0, at the outside of the wheel, is desired rather than the slip S_m, at the middle of the blade, it can be found by means of the following formula,

$$S_0 = 1 - \frac{(1 - S_m) R_m}{R_0}$$

R_0 is the radius of the outside of the wheel and R_m is the radius of the middle of the blade.

The eccentricity ratio is the ratio of E to L (see Fig. 6, Plate 94). If $E = 0$ the wheel becomes a radial wheel with fixed blades, and if $E = L$ the blades would not function properly. The eccentricity ratio is usually between 0.55 and 0.70. The effect of variation of eccentricity ratio upon thrust and efficiency can be seen in Fig. 7, Plate 94.

Larger values of eccentricity ratio are accompanied by a reduction of thrust and an increase in efficiency, dependent upon the slip. For each position of the eccentric and each dip of the blade there is a certain slip at which the blade will enter the water without disturbance. If the slip is less than this amount, there is pressure upon the back of the blade when it first enters, and if the slip is greater there is pressure on the driving face when the blade enters the water.

These curves would seem to indicate the desirability of using a true slip of about 15 per cent and an eccentricity ratio of about 0.55. While a larger eccentricity ratio would give a slight increase in efficiency, the thrust would be considerably smaller and a larger, heavier wheel would be needed.

The model wheels were tested with the center of the eccentric at the same level as the center of the wheel. Wheels are often made with the eccentric placed from 0 inch to 4 inches above the center of the wheel. It does not seem probable that this has any appreciable effect upon the thrust or efficiency.

The dip ratio is the ratio of the greatest immersion of the blade to the width of the blade. The thrust increases with increased dip but the efficiency falls off, as shown in Fig. 8, Plate 95. These curves show the desirability of using a true slip of about 15 per cent. The true dip used will depend upon what is of most importance in the design in hand, efficiency or power.

The object of the model tests was to determine the best proportions for stern-wheels on boats of moderate speed. The dip ratios used were between 1 and 1.5. In applying these results to side-wheels on boats of rather high speed it was necessary to extend the curves to dip ratios of 2.5. This was done on the assumption that the maximum thrust would occur when the wheel was immersed to the center

and that the thrust would be approximately zero when the wheel was fully immersed. The efficiency curves were extended on the assumption that when the wheel was fully immersed the efficiency would be approximately zero.

The pitch ratio is the ratio of the distance between the trunnions, measured on the arc of the circle, to the width of the blade. Fig. 9, Plate 95, shows how thrust and efficiency vary with this factor. These curves indicate that as a rule it would be better to sacrifice a little thrust in order to gain in efficiency. If a blade-width ratio of 0.16 is used, a pitch ratio of 1.85 would call for 9 blades, while a pitch ratio of 1.5 would call for 11 blades. At 15 per cent slip the unit pressure at pitch ratio 1.85 is 1.6 pounds and the efficiency is 0.668, while at pitch ratio 1.5 the thrust is 1.66 pounds and the efficiency is 0.64. Each of the 9 blades would have to be 4 per cent larger than each of the 11 blades, but the efficiency would be a little over 4 per cent greater, and the total blade area would be about 86 per cent of the 11-blade wheel. Some designers use a large number of blades to reduce vibration.

An attempt has been made to correlate the results obtained from model feathering-wheels with the trial trip results of full-sized wheels, and Figs. 10 to 13, Plates 96 and 97, show the relation between the two sets of results. The data for the full-sized wheels is given in Table I, Plate 90.

It is obvious that the location of the wheel relative to the bow wave is going to influence the working of the wheel to a large degree, and this quantity has been used as the abscissæ in plotting the results. In the determination of the wheel location relative to the crest of the bow wave it was assumed that the length of the wave created by the passage of the boat would be $.5573V^2$, and that the first crest would be 12 per cent of the wave length aft of the bow. V is the velocity of the boat in knots per hour.

It will be noticed that the maximum quantities do not occur at the wave crest but a little aft of it. This seems plausible when it is considered that the blades enter the water some distance forward of the center of the wheel and it is the first part of the stroke which is most effective. Also the wheels have considerable length, and the wave crests are not parallel to the axis of the wheel but rake aft. Another possibility is that the wave crest is more than 12 per cent aft of the bow.

The model wheels, when tested in the tank, were not adjacent to the hull of a boat, and by reason of this condition the dip observed when at rest would be very close to the dip when in motion. The apparent slip and true slip of the model wheel would be practically the same. The only condition tending to affect these would be the velocity of approach of the water to the wheel, which would be very small.

The paddle-wheel of a side-wheel boat is working under quite different conditions as regards dip and slip. The velocity of approach would be somewhat larger, due to the proximity of the hull. Due to the passage of the boat through the water there will be stream-line flow, wake, and waves.

The dip of the blades when the boat is in motion may differ considerably from the dip when at rest, depending upon the part of the wave in which the wheel is work-

ing. The true slip of the wheel will differ from the apparent slip because of the velocity of approach, wake, stream-line flow, and orbital motion of the water in wave formation. If the wheel is working in the hollow of the wave all of these except the wake make the true slip less than the apparent slip. If the wheel is working in the crest of the wave the wake and orbital motion are opposed to the stream-line flow and velocity of approach, and the true slip is probably greater than the apparent slip. It would appear, however, that the change in slip is much less in degree than the change in dip.

In addition to this uncertainty regarding the true slip and true dip of the full-sized wheels, there is further uncertainty regarding the variation of thrust with speed of advance. The usual assumption is that the thrust varies as the square of the speed of advance. The models were all tested at a speed of advance of 100 feet per minute while the full-sized wheels were moving at a velocity of about 2,000 feet per minute (see line 20, Table I). The model wheels were practically 1 foot in diameter, while the full-sized wheels were from 25 feet to 30 feet in diameter. According to the law of comparison the corresponding speed for the full-sized wheels would be about $100\sqrt{30}$, or about 550 feet per minute. The full-sized wheels are advancing at speeds which were three to four times the corresponding speed (see line 28, Table I).

With these three unknown conditions—namely, the variation of thrust with speed of advance, the variation of true dip from the observed dip at rest, and the variation of true slip from the apparent slip—it can be readily seen that there are a large number of relation factors which might be derived, depending upon the assumptions made regarding one or all of the unknowns. I have given here only two relation factors, one which I have called the virtual slip and one which I have called the virtual dip.

In Fig. 10, Plate 96, the relation factor is worked up on the assumption that the thrust varied as the square of the speed of advance, that the engine efficiency was 0.85, and that the wheel efficiency could be obtained from Fig. 5, Plate 93, by using the apparent slip and the apparent dip.

The unit pressure on a wheel advancing at the rate of 100 feet per minute was worked out (see line 36, Table I) and from Figs. 2 and 3, Plates 91 and 92, the slip that would give this unit pressure at the apparent dip was determined. This was called the virtual slip and the ratio of this to the apparent slip is given in Fig. 10.

The virtual slip was obtained by entering Figs. 2 and 3 with the thrust t (line 36, Table I) at the proper value of pitch ratio (line 14, Table I). Rising from this point to the apparent dip ratio (line 13, Table I), and then moving horizontally to the proper value of eccentricity ratio (line 17, Table I) a slip value was obtained which I have called the virtual slip (line 39, Table I).

It is obvious that the variation in dip is affected by the size of wave formed by the boat, and the size of the wave will vary with the speed-length ratio and the displacement-length ratio. The quantities used in Fig. 10 have been modified by using a wave factor equal to—

$$\sqrt[5]{\text{Speed-length ratio} \times \frac{\text{Displacement-length ratio}}{100}}$$

and the results are plotted in Fig. 11, Plate 96 (line 41, Table I). The dotted portions of the curves are simply suggestions as to the shape the curve might have; there are not enough points to determine it with any degree of accuracy.

The virtual slip factor is given because the quantities used in entering Figs. 2 and 3 fall within the range of the tests upon the models. The efficiency obtained by using the apparent dip may differ quite widely from the actual efficiency.

The extension of the curves for thrust and efficiency beyond dip ratios of 1.5 enables us to determine the other relation factor given in Figs. 12 and 13, Plate 97. This factor was determined by assuming that the thrust varied as the 1.75 power of the speed of advance, that the engine efficiency was 0.85 and that the wheel efficiency could be obtained from Fig. 5 by using the apparent slip and the virtual dip. The thrust of the full-sized wheels at a speed of advance of 100 feet per minute was determined from these assumptions. Figs. 2 and 3 were used to determine the dip ratio which would give this thrust at the apparent slip. This dip ratio divided by the apparent dip ratio gave the relation factor shown in Fig. 12, Plate 97.

The virtual dip ratio was determined by entering Figs. 2 and 3 with the thrust t (line 46, Table I) at the proper pitch ratio. A vertical line was drawn through this point. This vertical line was intersected by a horizontal line drawn through the point where the apparent slip intersects the proper eccentricity ratio. The intersection of these lines determined the virtual dip ratio.

The quantities used in Fig. 12 when divided by the wave factor gave the quantities shown in Fig. 13, Plate 97 (line 51, Table I).

It will be noticed in Fig. 12 that in the hollow of the wave there is a loss of dip of about 35 per cent, while in the crest there is a gain of about 60 per cent. A small portion of this loss and gain makes allowance for the fact that we have assumed the true slip to be equal to the apparent slip, whereas actually it is less in the hollow and more in the crest.

A study of the trochoidal wave shows us that the loss of dip in the hollow will be considerably less than the gain of dip in the crest. Fig. 14, Plate 98, shows half of a trochoidal wave. The center of the describing circle moves along the line AA. The line WL cuts the wave profile in such a manner that the area above WL is equal to the area below. If a ship of uniform cross-section were placed upon this wave, the line WL would represent its water-line in still water. If the ends of the vessel are fined away the ship will sink further into the wave to some such line as $W'L'$. It can be seen from the figure that the loss of dip in the hollow would be about half of the gain in the crest.

The assumption that the thrust varies as the 1.75 power of the speed of advance seems to give a reasonable variation of the dip along the wave.

For purposes of design either the slip factor curve or the dip factor curve could be used. The different points which determine the curves lie as nearly in a fair

curve as could be expected. An error of 1 per cent in the determination of the revolutions per minute would cause a change indicated by *A* in Figs. 12 and 13, while an error of 1 per cent in the determination of the speed would cause the change marked *B*.

Fig. 15, Plate 98, shows somewhat more clearly than does Table I the relation of speed-length ratio and wheel location to the quantity upon which the curves of Figs. 10 to 13 have been plotted.

DISCUSSION.

THE CHAIRMAN:—Is there any discussion on this paper on "Feathering Paddle-Wheels?" There are some experts on feathering paddles in the Society, I know. I do not know whether they are here this afternoon, but one of the greatest is absent, and I am trying feebly to take his place.

I may say that we are always glad to have any discussion submitted in writing, even if they are not received here in time to be given before the Society so that we all get the benefit of them at the meeting. Naturally, such written discussions as may be sent in will be submitted to the author of the paper so that he can take account of them in his summing up.

We are sorry that Professor Bragg is not here, so that he could personally receive the thanks of the Society for presenting this paper, which in your behalf I tender to him.

PROFESSOR BRAGG (Communicated):—Mr. Stevenson Taylor has very kindly furnished additional data for the City of Erie and Commonwealth, which enables me to add two points to each of the curves.

	City of Erie	*Commonwealth*
R. P. M.	28.4	28
Speed, knots	17.36	19.1
Apparent slip at outside of buckets	30.8	29.0
Displacement, gross tons	2400	5410
I. H. P.	4600	9050

These data give points which plot as follows on Figs. 10 to 13, Plates 96 and 97.

	City of Erie	*Commonwealth*
Abscissa value	1.08	1.2
Ordinate—Fig. 10	0.754	0.76
Fig. 11	0.797	0.844
Fig. 12	1.44	1.61
Fig. 13	1.52	1.79

THE CHAIRMAN:—We will now proceed to paper No. 15, entitled "Alquist Gearing for Ship Propulsion," by Mr. W. L. Emmet.

Mr. Emmet then presented the paper.

ALQUIST GEARING FOR SHIP PROPULSION.

By W. L. R. Emmet, Esq., Member of Council.

[Read at the twenty-third general meeting of the Society of Naval Architects and Marine Engineers, held in New York, November 18 and 19, 1915.]

The designs described in this paper are based upon the inventions of Mr. Karl Alquist. Mr. Alquist is an accomplished engineer and was formerly connected with the Turbine Department of the English branch of the General Electric Company, the British Thomson-Houston Company. His gear inventions were first brought to the attention of the writer early in the year 1911. For some time previous, Mr. Alquist had endeavored to arouse interest in his methods in England and on the Continent but had accomplished nothing. At that time the General Electric Company had not begun the commercial manufacture of high-speed spiral gears, but had for some time been conducting experiments to determine the limits of speed, pressure, etc., which were practicable with such gearing. The importance of high-speed gearing in connection with turbine and electrical applications is obvious and we were working with a view to development of the best standards.

Certain features of Mr. Alquist's proposals appealed strongly to the writer, and arrangements were made with Mr. Alquist to come to America and assist in experimental developments along the line of his inventions.

The result of this undertaking has been that many sets of gearing have been built and experimented with exhaustively under a variety of conditions, and by these experiments certain standards of practicability have been established and extensive commercial developments have been undertaken. Gearing of this character has been applied to about seventy-two sets where steam turbines drive electric generators of various types. Contracts have been closed for machinery for the propulsion of seventy ships aggregating 215,200 horse-power. Some of these electric generating sets have been in service one and one-half years and about seven of the ship sets are in service, some of them having made many long voyages. Among these are high-pressure cruising units for the battleship Nevada which have been in service for some time and shown very fine results. Among the ship equipments not yet completed are included the propelling machinery for Destroyer No. 69, built at Mare Island, and new propelling machinery for the scout cruiser Salem. In all of this practical experience no case of trouble with gearing has developed and no appreciable deterioration of gears has been observed.

One of the important reasons for adopting this type of gearing was that its design tended to afford a distribution of strains and means by which excessive strains would not be imposed upon any part through slight imperfections, distortions, or inaccuracies. The uniform success which has been accomplished with an entirely new

product shows that this expectation has been amply justified. Some of the gears which have been used have been very imperfect, both in the matter of material and workmanship, and have been used under extremely trying conditions. That they have not failed has afforded the strongest evidence of the general reliability of the method.

The character of construction used in this gearing is shown by one of the drawings (Fig. 1, Plate 100). The gear is built up of a number of plates machined to a form which gives them the desired degree of lateral flexibility. These plates are put together, engaging solidly at the hub and also engaging on a narrow edge at the periphery. When so built together they form a solid cylinder which can be spirally cut in the ordinary manner. After cutting, the edge engagements are relieved with a small dividing tool so that each disc operates independently and is free to deflect laterally under the side pressure which results from its diagonal engagement with the pinion. The parts are so proportioned that this lateral deflection can at no time involve fiber strains which could possibly cause destructive fatigue. A very small amount of this lateral deflection is sufficient to afford the desired distribution of load, and this amount can easily be given without approaching dangerous periodic strains.

To appreciate the value of this flexibility and load distribution, various peculiarities of solid and spiral gearing must be considered. In the first place, where gears are inflexible, there must always be a tendency to increase strain at the loaded end of the pinion through torsional deflection of the pinion. There is also a tendency to inequality of strain on different parts of the surface through the lateral deflection of the pinion under load. These inequalities can be partially compensated by elevating the bearings or evening the pressure on the bearings, but this compensation can only be partial because the correction applies only to the two ends and not to the middle. Furthermore, the momentary and periodic strains on different points of solid spiral gearing may be seriously affected by vibrations of supporting structures, irregularities of machine work or gear cutting, and other causes. If for any reason such conditions cause any tooth or part of a tooth to receive periodically excessive strains, fatigue may result and a broken tooth may destroy the whole gear.

To obviate the possibility of breakage under such conditions, it is often desirable in solid gearing to use relatively large teeth in order that these possible irregular strains on teeth or parts of teeth will not involve danger of breakage. For other reasons, however, the use of large teeth is distinctly undesirable in spiral gearing. Spiral gears tend to engage by point contacts at or near the pitch line, and the ability of these point contacts to bear pressure without fatigue of the surface metal is governed largely by the flatness of the surfaces engaging rather than by the size of the teeth carrying these surfaces. The flatness of the surface is a function of the pinion diameter and not of the pitch. If we double the number of teeth in a spiral gear we have twice the number of driving points in action, and the flatness of all of these points is the same in both cases if the pitch diameters are the same. These matters are illustrated in the sketches in Fig. 1, Plate 100.

With gearing of the Alquist type we can use very small teeth without any danger of incurring excessive strains on individual teeth, which might involve risk of the development of fatigue cracks. In this connection it should be borne in mind that experiments have shown that the strongest steel, if subjected to periodic deflections, will break after a fiber strain of 20,000 pounds per square inch has been applied a million or more times.

In the work which is now being done by the General Electric Company, gears of the type described are applied in three ways. First, a single reduction has been accomplished by engaging one solid pinion with a flexible gear of this type; second, by engaging a solid pinion with two flexible idlers, which idlers in turn engage with a solid large gear; and third, in a double reduction where a solid, high-speed pinion engages flexible gears on two counter shafts, these counter shafts carrying solid pinions, both of which engage a flexible gear on the same low-speed shaft. In these two latter applications the flexibility of the gears serves to equalize the loads between all of the driving points, and the use of a plurality of driving points on the large gear reduces the length of face necessary on that gear. These different methods of application are illustrated by diagrams in Fig. 2, Plate 101, and are also shown by the photographs and drawings of actual machines which are attached to this paper (Plates 102 to 108).

In both of these cases where a single high-speed pinion drives two flexible gears, other very positive advantages are accomplished. The pinion is relieved of bending strains, and pressure on the high-speed bearings is avoided.

Experiments have been made in Schenectady which carefully analyze the losses of high-speed gears under various conditions of load and pressure, and these experiments have indicated that low peripheral speeds are more efficient than high speeds. With solid gears, low speeds involve difficulties because they diminish pinion diameters and increase pinion lengths, thus complicating the troubles which may arise through deflection and torsion of pinions and pressure upon pinion bearings. Since the flexibility of Alquist gears enables us to compensate easily for all possible degrees of torsional yield in the pinion, we can with such gears safely reduce peripheral speeds by making the gears longer and of smaller diameter. Such reductions of diameter diminish weight and improve efficiency, and the fact that the Alquist method makes such reductions possible constitutes one of its important advantages.

The table (Plate 99) shows a comparison of performances for two sister ships, the La Brea and the Los Angeles, operated by the Union Oil Company of Los Angeles. Both of these ships are new, carry similar cargoes, and burn the same fuel oil in the same boilers under similar conditions. The La Brea is fitted with our geared-turbine equipment, and the Los Angeles is fitted with triple expansion engines of the best type. The Los Angeles is equipped with steam-driven oil-handling pumps of the ordinary type, and the La Brea is fitted with a new arrangement of pumps driven from the upper deck by General Electric motors. The table illustrates the superiority of the oil-handling machinery as well as that which propels the ships. The horse-power hours given in this table are calculated from the propeller and hull

data given by the naval architect of the Union Iron Works who built the ships, and based upon model tank experiments which were made in Washington. The models of the ships are identical, the La Brea propeller operating at 90 revolutions per minute and that of the Los Angeles at 65 revolutions per minute.

The seventh voyage of the La Brea and the sixth voyage of the Los Angeles were made over the same course and at nearly the same time. The relation of fuel economy of these two voyages almost exactly corresponds to that shown by the average of all the voyages and tends to verify the accuracy of the whole comparison.

DISCUSSION.

THE CHAIRMAN:—This paper on "Alquist Gearing for Ship Propulsion" is now open for discussion.

MR. LUTHER D. LOVEKIN, *Member:*—Mr. President and gentlemen, I notice that Mr. Emmet dwells on the economy of this particular type of geared propulsion. I would like to learn from Mr. Emmet whether or not, in view of the wonderful economies that have taken place with geared turbines, he is willing to consider the electric drive a thing of the past, or whether he expects to defend the same, in view of the disclosures made by other engineers relative to the geared drive; and if so, what grounds he has for favoring the electric drive other than that it has full power for reversing and shorter length of shafting.

We are about to build four battleships and four battle cruisers which will cost, exclusive of armor and armament, about $100,000,000, and these ships are specified to have the electric drive. Against this one of our eminent members has protested, but in vain—they must have the electric drive, because they were so specified.

It has been my pleasure to have the privilege of making the machinery layout for the battleships as well as the battle cruisers which are about to be built, and which have been arranged for the electric drive in both cases. I have made a most careful study of the same and completed plans for both vessels which satisfy me that I have ample proof that both vessels can be built with the geared turbines in a more satisfactory manner than they can with the electric drive. In other words, they can be built on less weight with the same protection, in the case of the battleships, and with more protection in the case of the battle cruisers, for in this latter case we can remove all the boilers from above the protective deck, whereas they now have half of the boilers above the protective deck.

I find that in the case of the battleships this can be done with one-half the weight of the electric-propelling machinery, and in the case of the battle cruisers on about one-third the weight of the electric-propelling machinery; in other words, the electric machinery will weigh about six million pounds, while the gear drive will weigh about two million pounds. Think of this difference in weight on a vessel of such an important character, and then think of what can be done with nearly two thousand tons of machinery weights which can be saved.

It seems to me Mr. Emmet knows as much about this subject as any one, and I know the Parsons people are building geared drives with a guarantee of 8.5 pounds of water per horse-power. If we have turbines capable of making the same water rate, driving the ship through gearing with 98 per cent efficiency, why should we adopt the electric drive which gives 95 per cent efficiency when we get the same water rate out of the original turbine?

It seems to me very peculiar that a Society such as the Society of Naval Architects and Marine Engineers is not represented as a Society on our Naval Board. I spoke to Secretary Daniels and asked him why the Society of Naval Architects and Marine Engineers was not represented on the Board. He said he thought it was.

Having made plans for these battle cruisers, I have every reason to believe we can secure a geared drive with the same economy guaranteed and of 2,000 tons less weight, and as the ships are constructed, we surely need this weight. Now, if there is anything except the fact that they have more margin in backing power, which matters very little, after all, and shorter length of shafting, I would like to know what other characteristic favors the electric drive; for surely as an engineer who has been designing the machinery for battleships for twenty-five years, and one who has laid out machinery for these battle cruisers, I would not say that I can put geared drive in the same space with more protection and greater economy unless I was prepared to prove it. If there is anything else left except the backing power and the shafting, I want to be advised of the fact, because I am going to write the Secretary of the Navy about it.

The Chairman:—The Chair has been rather liberal in the allowance of time for discussion, and I dislike to cut people short on their discussions, or on their introductions, but I must remind you that we have two other papers, and if the speakers who discuss the papers run much beyond the five-minute limit, I will have to ask them to cut short their remarks.

Mr. John H. Macalpine, *Member*:—The geared turbine is the most vital question before naval architects at the present day as it is transforming the whole field of marine propulsion. The reciprocating engine will now retire to second place after noble service. The direct-connected turbine may be said to be already obsolete. The turbo-electric drive will be looked back on as still-born—after the present little flurry in the United States is past—since it is far outclassed in every respect and for all sizes of ships, even the largest, by the geared turbine. Consequently, any article on the marine turbine or high-speed reduction gears is read with deep interest.

The present brief paper is principally remarkable for its omissions. It deals almost entirely in general statements, but gives no data from which the reader can form an independent opinion.

Near the bottom of page 182 we read, "Spiral gears tend to engage by point contacts at or near the pitch line." Why the author added "at or near the pitch line" I do not know, but the rest of the statement is well known to be correct for gears with rigid or fixed bearings. It is also true of the Alquist gear for reasons I will partly discuss. This is the author's opinion, for, on page 183, second paragraph, he twice uses the term "driving points" in connection with the Alquist gear. The statement is not true of gears in which the pinion is mounted in a floating frame. In an exhaustive article published in May and June, last, by *Engineering,* London, I have shown that theory points strongly to the floating frame producing line contact and from data which I there give in abundance this is confirmed; for a floating frame gear bears continuously and safely a load from two to three times as heavy as

that under which a rigid gear of the same dimensions usually is operated. I can assure Mr. Emmet that the "fearsome" picture he has conjured up, in the paragraph preceding that from which I have just quoted, of the disasters likely to follow the adoption of such gears from "the vibrations of supporting structures" have never been even suggested in a now extended experience.

My criticism of the Alquist gear will be directed to the form shown diagrammatically in the lower part of Fig. 2, Plate 101, but will apply largely to the other two forms. The high-speed pinion I will call Pinion *A*, and each gear meshing with it, Gear *A*; those of the second reduction I will call Pinions and Gear *B*. Those who have not studied high-speed reduction gears carefully may think that in what follows I split hairs and refer only to negligible values. But in this subject 1/1000 inch is a large and important quantity.

1. Pinion *A* is the well-known De Laval pinion. Mr. Emmet, near the bottom of page 183, claims that he can use Pinions *A* smaller in diameter and longer than is possible in other types of gear (though this is not borne out by his Fig. 5, Plate 104, which shows a Pinion *A* short in proportion to its diameter). Let us examine the result of adopting such a long, slender pinion unsupported in the center. Unless nearly equal powers are taken off by the two gear wheels meshing with it, this pinion bends excessively. This difficult condition has restricted its success, but the success of the Alquist gear depends on the condition being fulfilled almost perfectly. Mr. Emmet does not draw attention to this great difficulty, but it has been fully recognized by the designers of the Alquist gear and the means by which it is attempted to overcome it, as stated in the patents, is interesting.

In considering this it is first to be noted that the structure of the complete gear is redundant. This is evident since the gear would still run after we had removed one Gear *A* of the first reduction together with the Pinion *B* attached to it. But the power transmissible by the gear would then be greatly reduced, as the slender high-speed pinion would have no support against cross-bending. The number of teeth in Gears *A* and Pinions *B* are made prime to one another, so that if one of these gears is running as an idler it can be made to take stress by advancing it one or more teeth in its engagement with Pinion *A*. But, in a redundant structure, it would require the measurement of microscopic strains to tell if each part were taking its proper load and slight calculation, for a particular case will show that the adjustment provided is far too coarse, since the advance per tooth would be much greater than the strain under full load; and also much greater than could be compensated by any elasticity due to the laminations of the gears, so that this device is of little service here. In some earlier designs, Gear *A* drove Pinion *B* through a flexible shaft which helped matters a little, but that complicated the design and seems to have been dropped. Again, even if once adjusted for equal load on Gears *A*, slight straining of the gear case or wear or heating of a bearing would completely upset the equality. I regret that Mr. Emmet has not told us how this difficulty is overcome.

2. It would have been interesting had Mr. Emmet told us how the very flexible plates in Fig. 1, Plate 100, were machined so that the touching surfaces, at the center and outside, were all true and in the same plane. Ordinary methods of turning would hardly suffice even if the flexible plate were bolted down on a stiff, flat surface, for the side first bolted down is not finished true and the plate will usually be sprung. Should this not be accomplished with great accuracy the plates will be sprung when bolted together for tooth cutting; then when the parting tool separates them the strains will be relaxed and the teeth on contiguous disks will not be truly spaced, as when cut.

3. As torque is gradually applied to the small Pinion *A*, the highest stress will come on the disks of Gears *A* nearest the driving end, from which I will suppose we are looking in Fig. 2, Plate 101. These disks will bend, the contact points moving, say, toward us. This will allow stress to come on to the next disk, notwithstanding the torsional yield of the pinion; and as the torque increases further all the laminations will become involved, the yields of the disks changing in direction when we pass from the right-hand to the left-hand spiral, or vice versa. It is quite obvious that if the tooth pressure is to be nearly equal on all the disks, the yield of each disk at the point of contact must be many times the maximum torsional yield at the pitch line of the pinion. This proportion will increase, also, in proportion to the cotangent of the hellical angle of the teeth, which angle is about 30 degrees in Fig. 9, Plate 108. Thus the deflection of the gear disks, to be effective, must be very sensible. It appears from what I have just said, that in Fig. 2 the flexure of the disks of Gears *A* is such that vertical lines remain vertical after deflection, the tooth contact points in the near disk, as just supposed, coming toward us. I have stated this at length to call up a clear picture of the action. Obviously, on account of this bending, the originally true spiral teeth on Gears *A* are no longer true spirals; where there is contact the angle of obliquity of the gear tooth is increased, the velocity ratio is no longer constant, and there will be hard bearing on the points of the pinion teeth and roots of the gear teeth—that is, we will have point contact. No doubt the teeth would grind away, relieving this hard contact; we would then have untrue teeth bearing hard over small areas, the positions of which would change with changing load; the teeth would, consequently, be brightened all over and have the appearance of perfect bearing.

All this is increased in importance by the laminations or disks being few—five in each spiral of Gear *A*, and seven in each spiral of Gear *B*, Fig. 9. Thus the whole path of contact of one tooth may lie on one lamination, and the number of contact points on each Gear *A* will not be much, if any, greater than the number of disks.

4. Pinions *B* are subject to cross-bending. If Pinion *B* in the foreground of Fig. 9 is bent upward in the center, the axis of Gear *A*, to which it is solidly attached, will fall toward the left. At the same time the axis of the distant Gear *A* will rise toward the left. I have shown, in the article referred to earlier, that this strain is far from negligible, especially where, as in this case, a pinion is supported in two bearings only. Gears *A* are thus thrown in opposite directions out of their proper plane of rotation, as the total tooth pressure of Pinion *B* is much greater than that of Gear *A*; and this, in spite of the forward bearing of Gear *A*, as bearings have clearance. To correct this the disks would have to be distorted about the horizontal axis, Fig. 2, through the centers of Gears *A*. Against this strain they are enormously stiff, and the moments of the forces of tooth contacts *A* are nearly zero about this axis.

Further consideration would show that the wheels cannot be so handed as to make the "Third" and "Fourth" actions compensate one another.

Altogether, I prefer the line contact and easy adjustment of the floating frame gear to the small number of driving points and delicate adjustment of the Alquist gear.

5. It would have been interesting if Mr. Emmet had discussed why "low peripheral speeds are more efficient than high speeds," as stated in the second and last paragraph on page 183. High peripheral speeds will be accompanied by thicker oil films at the tooth contacts, which will go far to compensate for the greater rate of shear of the oil. But, granting the statement (though I think it is not correct within speeds in use), the advantage

which we can gain by diminishing the diameter of Pinion *A* and lengthening it must be exceedingly small since the peripheral speed varies as the pinion diameter and the linear torsional yield at the pitch line varies inversely as the third power of the diameter and directly as the length. Indeed, examining Fig. 9, one is struck by the small number of teeth which cross a longitudinal line on each spiral of Gear *A*—only about seven. So that the great advantage to be gained from a long pinion of small diameter and with fine pitch of teeth does not seem to have been followed up in practice. This also, as stated above, is not borne out by Fig. 5. If Mr. Emmet had given us the speeds, diameters, lengths, and tooth pitches for a reduction gear of a given power, we could have told exactly what some of his statements mean and what power constants he used. But he left us in the dark.

6. In all reduction gears the weight of the gear wheel is a very large proportion of the total weight, although usually it is a hollow structure. But in the Alquist gear it is nearly solid. This must so greatly increase the total weight of the reduction gear that it will become forbidding for destroyers and other warships where weight is so important. This is further emphasized if the small and long pinion is not used, necessitating an increase of the Gears *A* and *B*.

7. It is of great importance in ship propulsion that the engineer should have at least two strings to his bow. In the form of the Alquist gear I have been considering, which has been installed on some ships, there is only one turbine driving one pinion. If anything goes wrong with either of these in a single-screw ship, the engineer is helpless. I greatly prefer, both for safety and economy, a divided turbine driving two pinions.

Mr. A. C. Holzapfel, *Member* (Communicated):—I consider that the discussion on gearing for marine turbines will not be complete without some reference to the hydraulic gearing invented by Professor Fottinger. This gearing came out in 1910 when Professor Fottinger read a paper describing it before the German Institution in Berlin. It consists of the centrifugal pump delivering water to a water turbine, and was in the first place fitted to a small tugboat built by the Vulcan Company of this city, for home purposes.

Having at that time the intention to build a seagoing vessel driven by gas power derived from a suction gas plant, and being unable to obtain a reversible gas engine, I decided to adopt the Fottinger transformer not only for the purpose of reversing but also for reducing the revolutions of the gas engine, which were 480 per minute, to 120 on the propeller shaft. The transformer in question was the first commercial unit of the sort manufactured by the Vulcan Company and answered its purpose perfectly. There was a loss of about 16 per cent of power.

A number of larger transformers were subsequently built for the German Navy and mercantile marine, and when I last heard from my friends on the subject, there were transformers of more than 150,000 horse-power under construction by the Vulcan Company. The British patents were acquired by the firm of Beardmore, of Dalmuir, near Glasgow, but they did not at once start the construction. I have, however, recently received news that they have now started to built Fottinger transformers.

In 1912 I had discussions with Sir Charles Parsons about the Fottinger transformer. At that time, it was suggested by Professor Fottinger that the Parsons gearing would not be applicable to very large units, as, for instance, a battle cruiser, and Sir Charles seemed to give serious consideration to this suggestion at that time and was actually in negotiation for acquiring the Fottinger patent rights, presumably for the purpose of supplying this trans-

mission for the largest units. It has suggested itself to me that the American naval authorities may have been prompted by the same consideration in adopting electrical transmission instead of mechanical gearing for the battleships now building. I may say that, for large installations, the loss of power of the Fottinger transformer is only 6 to 7 per cent and that the reversing turbine can be dispensed with as the transformer does its own reversing.

The one I had on board my experimental vessel ran for two years with perfect results, excluding a few initial mishaps on the first voyage, and I believe this method offers many advantages which are worthy of the serious consideration of naval engineers.

THE CHAIRMAN:—Is there any other person who wishes to discuss the paper? Mr. Emmet, do you desire to make any verbal reply, or will you embody your reply in writing?

MR. LOVEKIN:—I do not know whether Mr. Emmet would care to give out any water rates on the electric drive, without which I cannot make a comparison that would be of value; but there is another point, and that is that while Mr. Emmet may be comparing the electric drive with the geared battleship, there are differences in geared battleships—some run at 15 pounds per horse-power, and others at 10 pounds per horse-power, so that unless you get the facts of both, it is impossible to make a proper comparison. I can say, however, that I believe we can design geared turbines suitable for speeds of from 35 knots down to 15 knots on a basis of steam consumption equal to any electrically-driven installation possible, and if Mr. Emmet will give his figures, I will give mine.

In all fairness to Mr. Emmet I will state that the comparison of electric drive with geared turbines is not based on his figures for the electric drive.

MR. EMMET:—In reply to Mr. Lovekin's remarks I will say that he may have studied electric-drive arrangements for these ships but that he has not studied those which I advocate, since no information on that subject has been either asked for or given. The figures as to weights are grossly incorrect, and he does not touch at all upon the most important reasons for the adoption of electric drive. His implication that such adoption has been in any way influenced by the Naval Consulting Board is entirely incorrect, the subject never having been discussed by that board or acted upon by it in any manner.

In reply to Mr. Lovekin's question as to my reasons for advocating electric drive for battle cruisers, I will submit the following which forms part of an article which I have recently written upon this subject.

The writer has for many years actively advocated electric drive for the larger vessels of the navy, and as a result of a long campaign of designing, experimentation, and educational activity, this method has been adopted on a large scale by our Navy Department. Electric-propelling machinery has been ordered for the last seven battleships which have been authorized, and is specified for the four new battle cruisers which form part of the present naval program. These battleships are very large and important vessels requiring 33,000 horse-power each, and the battle cruisers present the most stupendous propulsion problem ever presented, since they require no less than 180,000 horse-power each. Only two or three of our cities use as much electricity aswill be generated on one of these ships when she makes her full speed of 35 knots.

Electric propulsion has from the first had many opponents and it is still being very actively opposed by nearly all the shipbuilders of the country, by Sir Charles Parsons, Mr.

Chas. G. Curtis, and others who have had important influence in marine engineering. Most of this opposition is undoubtedly sincere, but is not altogether disinterested, since shipbuilders want to use machinery which they know how to build, and since turbine inventors have in the past received large royalties from turbine-driven ships which are cut off by the advent of electric drive. Although the power still comes from turbines, the electric drive is, by license agreements, free from royalty charges. The possibilities of large electrical apparatus do not appeal strongly to those who are not thoroughly familiar with its uses. Electric propelling machinery will be generally heavier and more expensive than the best developments of geared-turbine machinery, and variations of opinion have rested upon the relative importance given to advantages and disadvantages.

The General Electric Company has, under the writer's direction, also carried on extensive developments and operations in ship propulsion by turbines connected to ships' propellers by gearing. Machinery of this class for 79 large vessels has been contracted for by them, and many of these ships are in service and showing unqualified success. Our view, therefore, is not entirely one-sided, and although it may be considered that we are particularly interested in the development of the uses of electrical machinery, we believe that we have judged fairly and that our efforts will lead to important and lasting success.

In explaining the advantages of electric drive, comparisons will be made only with the geared-turbine drive. All other methods for propelling large vessels may be considered obsolete although many ships are still being built with engines or with direct-connected turbines.

A wise rule in engineering is to advocate new things only for the purpose in which they afford the greatest advantages, and this rule has been closely followed in the promotion of electric propulsion, which was originally advocated mainly for large warships. This first move was made before the use of mechanical gearing for such a purpose had been suggested, but its advantages for this particular use are so striking that it is still believed that the wonderful development of gearing possibilities have not changed the original case.

The subject of electric drive is too large for full discussion in such an article as this. Its possibilities and advantages can be best suggested by taking as an example the case of the new battle cruisers in which its use has been and still is the subject of much discussion and criticism. This may be considered as the extreme case where advantages are most important and in which the disadvantage of increased weight is most serious.

New Battle Cruisers.—Four of these vessels are authorized in the navy bill of 1916. They are designed to make 35 knots each, requiring 180,000 horse-power delivered to four shafts turning at full speed about 250 revolutions per minute. These are the fastest and most highly powered vessels ever built. The electrical installation proposed in each of them far exceeds in extent any single installation ever made for any purpose.

Apparatus Proposed.—It is proposed to install in these ships four high-speed turbine-driven generating units of the best type, similar in most respects to those used in power stations on shore. Upon each of the four propeller shafts will be mounted two independent induction motors. Cable connections and switching arrangements will be provided by which any combination of motors and generators can be immediately provided for and by which all the changes of connections for operation, reversal, etc., can be instantly made under all running conditions. The details of design and method of operation need not be described in this discussion. They are quite simple, in fact much simpler than in most electrical installations. The electric supply is produced for the one purpose of propulsion and is varied or

discontinued according to need. Connections are changed only on dead circuit, even in the ordinary operations of stopping, starting, and reversing, and automatic means are provided by which any diversion of current from any cause produces an unbalancing which instantly breaks the field circuit and de-energizes the system.

The aggregate weight of this equipment, with cables, switches, instruments, and controlling apparatus, is 1,865 tons.

Equipment if Gear-Driven.—If such a vessel were gear-driven, a plurality of ahead turbines would be connected through helical gearing to each propeller shaft, one or more backing turbines would also be connected through the same gearing, and if good cruising economy were sought, it would be necessary to provide also cruising turbines connected through separate systems of gearing and arranged with couplings so that they could be detached during high-speed operation.

A just comparison of this method with the electric equipment proposed would require a complete design and analytical study of the geared equipment and its performances. The writer has not made such a study in the case of these vessels, therefore no exact figures can be given. The space and number of turbine elements connected to each shaft will determine the space required for turbines, and this spacing will govern the length and weight of the shafts, piping, valves, and supporting structures.

In some of the installations which have been proposed abroad for vessels of much less power than these, the multiplication of parts has been very great and the size and extent of turbines and supporting structures such that the adoption of similar methods in these ships would certainly give weights nearly as great, if not greater, than those proposed for the electric drive. Some of our shipbuilders, in bidding to the government on these vessels, have stated that by using geared equipment they could save about 1,000 tons in weight and about $1,000,000 in cost, but whether these statements will bear analysis or not cannot be said without study of their detailed designs, if any have been made.

Detachment.—Without further description or discussion of either type of apparatus, we are in a position to make a comparison which constitutes one of the most important advantages of electric drive. In the geared equipment, each shaft has a system of turbines, gears, bearings, thrust balancing devices, and lubricating systems, all mechanically locked together. With high-speed machinery any kind of trouble with any of these parts will almost certainly necessitate the immediate stoppage of the whole system. To keep a high-speed turbine running out of balance or with bearing trouble is impossible, and the gearing part would present almost equal difficulty. In the event of mechanical trouble of such character, a ship would have to be stopped until the wreck could be cleared. The work necessary to uncouple and disconnect any part of such very heavy apparatus would be a serious matter, involving much time, including that required to stop the ship. After the disconnection was made the idle propeller would act as a very serious drag on a fast vessel.

In the electrically driven ship there is no mechanical connection of the shaft to anything but the rotors of motors. These are self-contained, iron-clad structures and cannot by any possibility be subject to mechanical interference. The shafts are subject to the same possibilities of bearing or thrust trouble as shafts in other ships, but the presence of the motors does not increase this danger, and the speed being low it is remote in any case. With this equipment any motor, generator, or turbine, if in any kind of trouble, can be instantly disconnected without stopping the ship and with only a small loss from the highest speed capacity.

Interchangeability.—Such interchangeability as this power of disconnection gives constitutes one of the most important advantages of electric drive in such a ship. With one motor out of eight in trouble, only one-eighth of the maximum capacity is lost and the ship's maximum speed is impaired by only about 1 knot. If a generator or turbine is in trouble, the maximum speed is reduced only about 2 knots. With two generating units and four motors out, the ship can make 26 knots; and with three generators and four motors out, she can make 19 knots. If parts give trouble, they are simply cut out and repaired at leisure or as opportunity affords. The value of this interchangeability in a warship can hardly be overestimated; it largely overcomes the military danger incident to accidents to the driving power, a danger which has always been of primary importance.

Backing Power.—In turbine-driven ships, not electric, it is necessary to provide backing turbines which must run idle in the reverse direction when the ship is going ahead. These backing turbines involve complications which are very objectionable, and if these are reduced to a desirable minimum the backing power will be greatly inferior to that easily provided with electric drive. Experiment has shown that a turbine forced in an opposite direction involves about seven times as much friction loss as when driven in its normal direction. This loss is very appreciable in the backing turbines of ships and causes heating which must be dissipated by circulating steam, which causes further loss and waste. There are also serious difficulties and dangers in high-speed apparatus incident to the abrupt and wide changes of temperature where steam is suddenly admitted to a cold reversing turbine. Steam which expands without doing work has a high temperature and, if work is done upon it by a reversed turbine, the heat is considerably increased. With superheat these temperatures may be extreme and they affect the main turbine as well as the other, since it also must be used for reversal of direction and since the two often occupy the same casing. The mechanical effect of such abrupt change of steam temperature upon fragile structures presenting very extended surfaces is a matter which has been little considered but which has caused much serious trouble. With electric drive the turbine never need be stopped when the ship is under way, and its operation is easier than in a power station because the load is steadier. With modern high-speed turbines, superheat affords large gains in fuel economy, and the ability to safely use high degrees of superheat may constitute one of the important reasons for adopting electric drive.

Efficiency of Transmission.—Various statements and estimates have been published concerning losses in high-speed gearing for which the authority is not known by the writer. Tests at Schenectady have shown losses about double those generally estimated, with rapid diminution of efficiency as load falls. These tests were of a most accurate character with large smooth-running gears and by the motor generator method where losses alone were measured, the same power being transmitted with and without the gearing.

With the electric drive in these battle cruisers, the losses from turbine to propeller shaft at full speed will amount to 7 per cent, and by adjustment of voltage the transmission efficiency can be kept equally good at all speeds. Considering gearing losses, reversing turbine losses, losses incident to necessary subdivisions of the turbine and additional packings, it is believed that the actual transmission from turbine blades to shaft at full speed cannot be made more than 2 per cent better in the geared equipment than it is in the electric. At reduced loads the geared equipment will be much less efficient. The normal cruising speed of these ships will require less than one-tenth of full load, and the drag of gearing, bearings, reversing turbines and idle parts of main turbines will be very serious. Some of these mat-

ters seem to have been ignored in statements which have recently been made on the subject.

Cruising Economy.—With the electric design, the number of motors and turbines used can be adapted to the demand for power, while with the other all parts must be kept running. This gives very important gain in economy at all speeds below the maximum. At 19 knots only one turbine is required to drive the ship, and electrical arrangements are made by which it can be run at full speed instead of running at half speed, as it would if the ratio were fixed as by gearing. Thus the steam efficiency at 19 knots, a desirable cruising speed, is equal to the best attainable at any speed. Assertions which have been made by shipbuilders and others that equal cruising results can be obtained by the use of cruising turbines are obviously absurd. The cruising turbines themselves would be greatly inferior to the single main turbine so used, and they would be burdened with all the drags which are mentioned above. Cruising economy gives increased cruising radius without renewal of fuel supply. This has always been considered a matter of the greatest importance in warships; it is a feature in respect to which electric drive can have no rival.

State of Development and Expediency.—Enough has been said to give an idea of the reasons for the use of electricity in such ships, but in addition it should be considered that everything used in such an electric installation is a matter of exact knowledge and wide experience, while methods of gearing on such a scale are backed by little and brief experience and are the subject of wide difference of opinion as to methods of design and proportions.

The writer believes that the differences of weight and cost which have been predicted by shipbuilders and others are not based upon just comparisons, but that even if they are true they are not sufficient to balance the practical merits of electric drive for such vessels.

For these reasons it is believed that when prejudices are overcome, electricity will develop an extensive use in large high-power warships. In such light vessels as scouts and destroyers, for reasons of weight and space, it is relatively much less desirable, but even in such cases with the lightest and most compact designs and with very high pressure and superheat, it might in the future develop a legitimate application. In merchant ships also it may afford great advantages. With electricity, turbine units can be installed in duplicate, either in single or twin screw ships. Machinery can be installed where convenient with motors near propellers and turbines near boilers; auxiliaries can be driven electrically from the main units. The highest superheat can be used without danger or complication, and main units can be applied to other power uses such as cargo pumping or handling. These advantages have led to the preference of electric drive at a higher price in certain large freighters recently ordered, and will doubtless lead to many other applications in ships of various types.

The advantages here mentioned have been developed with a wonderful skill and foresight by the Swedish engineer Ljungstrom in the 900 horse-power ship Mjolner which has been in successful operation for about two years. This vessel has shown a fuel economy decidedly superior to anything produced elsewhere in a steamship, and has maintained this high standard throughout her period of service. Such a result with such small power is very remarkable and significant. The Mjolner uses an extremely high degree of superheat.

In reply to Mr. MacAlpine's discussion of my paper I can only repeat that the apparatus works and that its performances show no indication of difficulties through the deficiencies which he mentions. In large vessels in which these gears are operated the sound is hardly noticeable even in the engine-room and the surfaces of the teeth have acquired a

glassy polish which indicates a perfect distribution of strains as contemplated in the design. I believe that the uses of this form of gearing are to-day as extensive, if not more extensive than those of any other high-speed helical gearing which has been applied in this country. In all of these applications the success of the Alquist gears has been uniform and every gear which has been built has been put into successful service, whereas some serious troubles have been encountered with gears of other types, and I know of cases of very serious delays on account of the necessity of rebuilding gears. My paper states the character of our construction and our reasons for adopting it, and I think there is no reason why I should add anything further to the discussion.

The Chairman:—We will consider the discussion on this paper closed, and proceed to paper No. 16 entitled "Electric Pumping Equipment and Notes of Interest on the Union Oil Company's Tanker La Brea," by Mr. H. P. Frear, Member. In the absence of Mr. Frear, it will be considered that this paper is now before you.

ELECTRIC PUMPING EQUIPMENT AND NOTES OF INTEREST ON UNION OIL COMPANY OF CALIFORNIA'S TANK STEAMER LA BREA.

By Hugo P. Frear, Esq., Member.

[Read at the twenty-fourth general meeting of the Society of Naval Architects and Marine Engineers, held in New York, November 16 and 17, 1916.]

The S. S. La Brea is the first tank steamer equipped with independent submerged cargo pumps in each compartment, port and starboard, operated by electric motors on deck, and also the first to be fitted with reduction gear turbines, so far as the writer knows. Otherwise the vessel differs little from many tankers built on the Isherwood longitudinal system of framing, and therefore these two items, especially the electric pumping system, will receive the most attention.

The La Brea is 435 feet in length, 56 feet in breadth, and 33 feet 6 inches in depth, moulded, and was the first vessel of this particular class built by the Union Iron Works Company, San Francisco. The contract was dated May 14, 1915, and delivery made February 29, 1916.

There have since been completed or contracted for, by the same builders, thirteen additional tankers off the same scrieve, all with pump rooms and ordinary pumping systems except one vessel for the Pan American Petroleum Transportation Company, which will have the same pumping system as the La Brea, but with only one pump to each transverse cargo compartment in lieu of two as fitted on the La Brea.

Ten of these additional tankers have reduction gear turbines and three triple-expansion reciprocating engines of approximately the same indicated horsepower as the shaft horse-power of the turbines. In each case the length of machinery space, forehold and overall length of the oil compartments, including pump room and coffer-dams, are the same. The position of the pump room, coffer-dams, length of fuel tank and length of some of the cargo tanks vary more or less to suit the owners' views.

Of this class, the tanker following the La Brea was the Los Angeles, also for the Union Oil Company of California, but fitted with triple-expansion reciprocating engines, pump room and ordinary pumping equipment of standard capacity and efficiency. These two vessels, delivered within a month of each other and owned and operated by the same company, offer a most excellent opportunity for a general comparison of their performances on the voyages so far completed.

For a general description of the La Brea the reader is referred to Fig. 1, Plate 109, showing a photograph of vessel afloat and Fig. 2, Plate 110, showing profile inboard and decks. On account of the limited scope of this paper, attention is called

only to the reduction gear turbines and location of cargo pumps and motors indicated on the profile inboard and upper deck. Tanks 1, 2 and 3 are much smaller than the remaining tanks and have an independent discharge line. These were intended for light distillates, but have not been used for that purpose up to the present time.

The propulsion equipment was furnished by the General Electric Company and consists of a Curtis turbine of the type developed for ship-propulsion work, operating at a speed of 3,500 revolutions per minute, direct-connected to a double reduction gear suitable for reducing the speed of the turbine to 90 revolutions for driving the propeller (see Fig. 3, Plate 111). The normal rating of the turbine and gear is 2,600 brake horse-power, with a steam pressure of 200 pounds at the throttle valve, 50 degrees superheat and exhausting into a vacuum of 28½ inches, measured at the exhaust inlet with the barometer at 30 inches.

The steam turbine consists of a forward 5-stage element and a 2-stage reversing element mounted on the same shaft and exhausting into the same chamber (see Figs. 4 to 6, Plates 112 to 114). Control of these turbines is effected by means of a throttling lever actuating balanced valves located respectively in the steam lines to the ahead and reverse turbines. Speed of the turbine is controlled by throttling, and there is also provided a hand-operated stop-valve in the reverse line which is normally kept closed while at sea, in order to prevent any possibility of leakage of steam into the reversing turbine. This valve is opened when it is desired to maneuver or make a landing.

The ahead turbine consists of five Curtis stages as stated above, the first or high-pressure stage carrying two rows of buckets and the remaining stages a single row of buckets. The buckets for each stage are mounted on a rolled steel plate wheel, into the periphery of which the buckets are dovetailed in a manner developed by the General Electric Company and successfully used for many years to meet the severe requirements of central station turbines. Steam enters each stage successively through nozzles carried in the diaphragms between each stage.

The reversing turbine is of the same construction as the head turbine, with the exception that it consists of two stages only, of smaller diameter. The reversing turbine is capable of developing two-thirds torque and two-thirds speed with the same steam flow taken by the ahead turbine under normal operating conditions. The nozzle capacity, however, is greater than that of the ahead turbine, so that the requirement of reversing power may be considerably exceeded under normal operating conditions.

The reduction gears are of the helical type and arranged to give two speed reductions, the high-speed reduction ratio being 5.03 and the low-speed reduction ratio 7.75, making a total reduction ratio of 39.1. The high speed or driving pinion meshes with the two gears, one on each side, the three shafts lying in a horizontal plane. The low-speed pinions are mounted on the same shaft as the high-speed gears. The adjustment is such that work is divided equally between the two low-speed pinions.

The high-speed gears are built in accordance with the "Alquist" patents and

consist of a number of rolled steel plates, each 1 inch thick and thinned out near the center in order to give a certain degree of flexibility, thus insuring equal distribution of the work through the total face of the teeth. This construction has been found not only to give smoothness and lack of noise in operation, but has also resulted in a great reduction in the wear of the gears and pinions.

Slip couplings are provided between the high-speed gears and low-speed pinions in order to prevent any movement of the main thrust shaft being transmitted to the turbine.

The turbine bearings and gears are supplied with oil under pressure of about 10 pounds. The oil is circulated by means of steam pumps which take oil from the main tank, where it is first forced through a strainer and then through a cooler before being delivered to the turbine bearings and the spray nozzles delivering oil to the gears. Oil is also supplied under pressure to the various bearings of the gears and pinions.

The complete weight of the turbine and reduction gear, including all parts for the throttle valve and thrust shaft coupling, is about 110,000 pounds.

The electric cargo pumping system is the result of much labor and study on the part of Mr. O. B. Kibele, General Superintendent of Transportation for the Union Oil Company of California, who, with the able assistance of the San Francisco office of the General Electric Company, perfected all of the details. The writer is indebted to both for much of the material worked into this paper.

The installation consists of twenty-two Ideal 4-inch rotary pumps, built by the Union Tool Company, Torrance, California (Figs. 7 to 9, Plates 115 to 117), and are designed especially for handling highly viscous oils, molasses and creosote, and are also fitted with a steam jacket for handling asphaltum. Each pump can deliver 350 gallons per minute against a total head of 350 feet at 200 revolutions per minute. The pumps are secured in the bottom of each compartment of the vessel, port and starboard, to brackets that are integral with the tanks, and are driven by 40-horse-power, 3-phase, 60-cycle, 220-volt motors. The discharge line for the three small tanks forward have nine 4-inch discharge gates, while the separate discharge line for the remaining tanks have fourteen 6-inch discharge gates.

The motors are located on the upper deck contained in a watertight and gas proof casing (Figs. 10 and 11, Plates 118 and 119). The drive to the pumps is through a set of bevel reduction gears and a vertical shaft which transmits the power through flexible couplings to the pumps.

The shaft is entirely enclosed in a casing which serves as an oil reservoir, so that all of the shaft bearings and the pump gears are operated in an oil bath.

The pumps are each fitted with enclosed carbonized spiral gears, top and bottom, and operate with a minimum of noise. The vertical-drive shaft is hung on a ball thrust bearing contained in the gear case. They are fitted with 6-inch suctions and 6-inch discharges, so arranged that each pump can take suction from either or both compartments, port and starboard, at the same time, or independently. Cargo may also be discharged with one pump or as many pumps as can be put into oper-

ation at one time, depending entirely on the capacity of discharge pipes to the shore tanks. Any number of commodities can be discharged at the same time without mixing, depending, of course, on the number of discharge lines that are available to the shore tanks. The discharge lines from the pumps are so arranged that they can be also used as filling lines to each individual tank, by means of a bypass around the pump.

Both Mr. Kibele and the writer, from the start, believed that half the number of pumps would meet all requirements, but finally decided to take no chances on the first installation. The better and more economical plan would be to connect the smaller number of pumps to a common 6-inch suction line, fitted with gate valves at each bulkhead and independent suction to each tank. This would enable each pump to draw from all or any of the tanks and insure maximum flexibility in the event of one or more pumps going out of commission.

All operating valves are located on the upper deck. The motor control for starting the pumps is located in the main engine-room and will be described in more detail hereafter. When it is desired to start any particular pump, the deck officer gives the signal to the operator in the engine-room. Pumps are thus under direct control at all times by the engineer on watch.

Since the La Brea went into commission she has handled over 500,000 barrels of oil, and in each case the discharge was completed with a material saving in time as compared with vessels with ordinary pumping system.

The capacity of the pumping system is, of course, regulated by the capacity of the discharge lines and the pressure that the pumps are subject to. On a low-discharge head, and with ample shore connections, the entire cargo could be discharged in approximately 10 hours time. The maximum quantity of oil handled per hour against a pressure of 110 pounds per square inch is reported to be 4,200 barrels.

The economy in fuel saved with this pumping installation appears to be approximately 45 per cent over the ordinary manner of discharging a liquid cargo.

After it was determined to use this system of pumping, with a pump in each individual tank, the most logical way of driving the pumps was by independent electric motors. In determining the proper type of motor, several propositions were considered. Inasmuch as the drive of the pump was vertical, both vertical and horizontal motors were considered. Twenty-five cycle would have permitted using a slow-speed vertical motor suitable for direct connection to pump without any gearing, but this necessitated the installation of special 25-cycle turbine generating sets. The higher speed of 60-cycle motors required connection to pump through vertical gears if vertical motors were used, and this was not considered practical. The horizontal motors, whether 60 or 25 cycle, required the use of bevel gears. All the power companies operating on the Pacific coast and the various refining and loading stations of the Union Oil Company use 60 cycle, and the installation of 60-cycle motors had the advantage of being able to use shore power to drive the cargo pumps if required. For this reason, and also on account of long shipments required for the vertical 25 or 60-cycle motors, it was decided to use the horizontal 60-cycle type.

Work had been progressing very rapidly on the hull construction, but the motors and generating apparatus could not be ordered until after the amount of power required to operate the pump had been determined. An experimental pumping plant was installed, and it was some time before the data were available, with the result that shipment became very important and was the deciding factor why certain types of motors, etc., were selected. The cargo motors are installed, as previously stated, on the main deck, exposed to weather conditions and salt water, and so it was decided to use the open type and to enclose the same in a water-tight casing supplied by the builder.

Ordinarily the pumps and motors would be required to start up against line pressure, and this would necessitate a high-starting torque slip-ring motor with its necessary starting resistance and controller. With this type of motor there is sparking at the collector rings and the controller fingers, and, as the motors would be installed on deck where explosive gases might be present, it was not considered practicable to use the same; consequently it was decided to use the ordinary squirrel-cage type. This motor, however, does not have torque sufficient to start a pump against full line pressure, and it was necessary to install a bypass on the cargo pumps. Pumps are brought up to full speed with the bypass open, which is gradually closed, at the same time opening up the valve in the discharge line.

As already stated, there are twenty-two of these cargo pumps, and each is equipped with a motor of the following rating:—40 horse-power, 600 revolutions per minute, 3 phase, 60 cycle, 220 volt, horizontal, squirrel cage of the open type construction (Fig. 12, Plate 120).

The motors are enclosed in a water-tight casing, as stated above, and this was made of cast iron. When loaded it is necessary for the motors to have proper ventilation, and the enclosing case is equipped with several hand-hole covers, which are opened when the motor is in service (Fig. 10, Plate 118). The motors ordered for the next installation are exactly the same, except they are enclosed and no additional water-tight casing will be required.

In addition to the cargo pump motors the following motors were installed in the engine-room, depending on the same power plant:—

One 60 horse-power, 720 revolutions per minute, 3-phase, 60-cycle, 220-volt, horizontal open-type motor, direct connected to circulating pump for main condenser.

One 50 horse-power, 3,600 revolutions per minute, 3-phase, 60-cycle, 220-volt motor, direct connected to one boiler feed centrifugal pump.

One 35-horse-power, 1,800 revolutions per minute, 3-phase, 60-cycle, 220-volt motor, direct connected to centrifugal ballast pump.

The power plant is located on a gallery over the thrust shaft at the after end of the engine-room and consists of two turbo-generating sets:—

One 375 K-va, and one 125 K-va, 3,600 revolutions per minute, 3-phase, 60-cycle, 240-volt generators, direct connected to General Electric Curtis condensing turbines, with direct-connected exciter (Fig. 13, Plate 121).

These turbines exhaust into the auxiliary condenser, but it is also arranged so that they can exhaust into the main condenser. While discharging, the larger turbine is of sufficient size to operate nine pumps at about 140 pounds pressure, and for general purposes this is the maximum number of pumps that can be operated at one time with present shore discharge lines. However, necessary arrangements are made to operate both generators in parallel, making a total capacity of 500 K-va; this would permit the operation of eleven to twelve pumps at the same pressure. In case of any trouble with the large turbine, the smaller unit could be used to operate two to three of the cargo pumps. When at sea, the 125 K-va turbine is used, exhausting into the main condenser; this turbine is of sufficient size to operate the boiler feed, main circulating pump and lights. In case of any trouble with the 125 K-va turbine, the larger turbine could be used. With the above arrangement there is always one turbine available as a spare.

For furnishing lights, there are supplied two transformers stepping voltage down from 240 to 120. To furnish the necessary power for the lights when both the above turbines are shut down, there is a small 5-kilowatt, 125-volt engine-driven, direct-connected generator available.

The switchboard is shown on Fig. 14, Plate 122, and is installed on a gallery on the starboard side of the engine-room. Starting from left to right, the switchboard consists of the following:—

One swinging bracket, one synchronizing device, used for paralleling the two turbines and the voltage regulator.

Panel 1 controls the two direct-connected exciters of the turbine sets.

Panel 2 controls the 125 K-va generator set.

Panel 3 controls the 375 K-va turbine set.

Panel 4 controls the feeder lines to the motors in the engine-room and the compensators used for starting the cargo pump motors.

Panels 5, 6 and 7 control the twenty-two circuits to the cargo pump motors.

Panel 8 is the lighting panel and controls the 5-kilowatt generating set and the auto transformers which changes the voltage from 240 to 110. It is so arranged that lights can be operated either from the main generating sets or the small auxiliary 5-kilowatt set.

One of the novel features in connection with this installation, and which is part of the switchboard, is the method of starting the cargo pumps. Ordinarily the practice is to use a starting compensator with each squirrel-cage motor. For various reasons it was not considered advisable to use any starting devices where the circuit would be made or broken on the upper deck, on account of possible presence of explosive gases, and a scheme was worked out by which all the motors were started from the engine-room switchboard.

Arrangements were also made to start all motors from two compensators, one of which is a spare. This is accomplished as follows:—The three panels, 5, 6 and 7, controlling the cargo pump motors, have running and starting buses, the running bus energized direct from the generators, and the starting bus through the compen-

sators. The starting bus is not energized until the contactor at bottom of panel 4 is closed. The switches starting the motors are triple pole, double throw. The upper contacts are connected to the starting bus and the lower contacts to the running bus. When the switch is thrown into the upper position, the blades engage the contacts, but no power is available until the switch is pushed all the way in, which closes a small auxiliary contact, which in turn closes the main contactor on bottom of panel 4. This in turn energizes the starting bus through the compensators, and the motors start. An ammeter is installed in the starting circuit, which indicates when the motor is up to speed. When the motor is up to speed the motor switch is thrown into the lower position—that is, on the running bus—and the motor is then operating on full voltage. When throwing the motor switch from the upper to lower position, the auxiliary contact is the first to open, which in turn opens the main contactor, with the result that the making and breaking of the starting current is made on the main contactor. Each motor circuit is supplied with three fuses, installed on the rack back of the switchboard to protect the motors from overload.

In order that the searchlight could be operated from the main alternating-current generators or the 5-kilowatt direct-current auxiliary generator, the direct-current mechanism was removed from the searchlight and replaced with a high-power concentrated filament incandescent lamp. This was tried out and worked very satisfactorily.

The data in Tables I and II (page 203) have been compiled from logs on voyages to date, respectively, for the La Brea and Los Angeles and give a very good general idea of the comparative performances of the two vessels and their equipment. The methods employed by companies in measuring oil into and out of a vessel sufficiently guarantee the accuracy of this data for general comparison.

Comparing the time in port discharging, and barrels of oil discharged per hour for the first six voyages, the La Brea was in port 36.4 per cent less time and discharged 55.4 per cent more oil per hour than the Los Angeles. If we reverse the order, it will be noted that the Los Angeles was in port 57.04 per cent more time and discharged 35.67 per cent less oil per hour than the La Brea.

By referring to voyage seven of the La Brea and voyage six of the Los Angeles, it will be observed that the destination in each case was Antofagasta, Chili, and that the Los Angeles preceded the La Brea by two days. Notwithstanding the La Brea had been out of dock a month longer than the Los Angeles and a greater time in warm water, it is stated that she could have overhauled the Los Angeles and discharged first had the contrary not been arranged.

Table III (page 204) gives separately a comparison of these two voyages on which the weather conditions are reported as follows:—

La Brea:—July 1 and 2, rough following sea; July 3 to 7, fine weather; July 8, rough; July 9 to 12, fine weather; July 13 to 22, strong head wind and sea; July 23 to 30, fine weather; August 1 to 9, strong southwest wind and sea.

Los Angeles:—June 29 to July 5, fine weather; July 6 to 10, fresh head wind and sea; July 14 to 17, strong head wind and sea; July 18 to 28, fine weather; July 29 to August 7, moderate head wind.

It will be noted that the La Brea consumed 17.09 per cent less fuel steaming, 42.47 per cent less fuel in port, 44.92 per cent less time in discharging, 17.43 per cent less fuel per knot steaming, 17.92 per cent less fuel per knot steaming and in port, and discharged 83.65 per cent more barrels of oil per hour.

The length and size of discharge pipes and pressure pumped against at discharging ports are reported to be as follows:—

Oleum—one 10-inch pipe, 2,000 feet long, pressure 140 pounds.

Seattle—one 8-inch pipe, 1,500 feet long, pressure 140 pounds.

Taltal—two 6-inch pipes, 250 feet long each, branching into one 8-inch pipe 200 feet long, pressure 80 pounds.

Antofagasta—two 8-inch pipes, 2,100 feet long, pressure 85 pounds.

The temperatures and gravities of oil while being discharged on the seven voyages are as follows:—

Voyage	*Temperature*	*Gravity, Baumé*
No. 1	64°F.	25.9 Refining crude
No. 2	56°F.	18.0
No. 3	62°F.	15.5
No. 4	73°F.	16.8
No. 4	70°F.	17.4
No. 5	60°F.	26.3 Refining crude
No. 6	64°F.	18.1
No. 7	64°F.	16.7

Not over eight or ten pumps should be operated in connection with a 12-inch shore line according to pressure.

TABLE I.—*S. S. La Brea.*

Voyage	Date	Distance	Average speed per hour	Delivered	Port	Fuel used steaming on voyage	Per knot steaming	Used in port	Per knot steaming and in port	Time in port	Discharged per hour	Cost*
		Knots	*Knots*	*Barrels*		*Barrels*	*Barrels*	*Barrels*	*Barrels*	*Hours*	*Barrels*	
1.....	Mar. 9 to Mar. 15	650	9.5	62,578	Oleum	574	.883	142	1.10	36½	1,714	.880
2.....	Mar. 15 to March 26	2,037	11.33	73,600	Seattle	1,459	.716	152	.790	37½	1,962	.632
3.....	Mar. 28 to Apr. 6	2,108	11.01	64,676 8,642	Vancouver Seattle	 1,584	..... .751	 155	..... .824	26 13½	2,487 640	..... .659
4.....	Apr. 8 to May 16	9,254.5	10.97	52,109 9,045	Taltal Antofagasta	 6,896	..... .745	 117	..... .757	33¾ 15½	1,544 1,228	..... .605
5.....	May 17 to May 23	450	11.2	77,292	Oleum	321	.713	134	1.01	39	1,980	.808
6.....	May 24 to July 1	9,196.5	10.65	71,824	Antofagasta	6,900	.750	109	.762	25	2,660	.609
7.....	July 1 to Aug. 9	9,184	10.39	71,791	Antofagasta	6,875	.748	107	.760	31	2,316	.610
Total	.....	32,880	10.72	501,557		24,609	.748	916	.776	.....	2,418	.621

*At 80 cents per barrel per knot steaming and in port (full).

TABLE II.—*S. S. Los Angeles.*

Voyage	Date	Distance	Average speed per hour	Delivered	Port	Fuel used steaming on voyage	Per knot steaming	Used in port	Per knot steaming and in port	Time in port	Discharged per hour	Cost*
		Knots	*Knots*	*Barrels*		*Barrels*	*Barrels*	*Barrels*	*Barrels*	*Hours*	*Barrels*	
1.....	Apr. 9 to Apr. 15	423	9.4	67,074	Oleum	556	1.31	164	1.70	64½	1,039	1.36
2.....	Apr. 16 to Apr. 25	1,845	10.13	74,739	Vancouver	1,656	.897	218	1.01	33¾	2,214	.808
3.....	Apr. 27 to May 25	6,549	10.22	73,734	Panama	5,579	.851	169	.877	46¾	1,577	.701
4.....	May 26 to May 29	220	9.1	72,592	Oleum	221	1.00	123	1.56	41	1,770	1.24
5	May 30 to June 27	6,348	10.6	72,538	Balboa	5,462	.860	159	.885	35	2,072	.708
6.....	June 29 to Aug. 7	9,151	10.24	71,007	Antofagasta	8,293	.906	186	.926	56¼	1,261	.741
Total	.....	24,536	9.95	431,684		21,767	.887	1019	.928	.....	1,556	.723

*At 80 cents per barrel per knot steaming and in port (full).

TABLE III.—*Voyage 7, S. S. La Brea, Compared with Voyage 6, S. S. Los Angeles.*

	La Brea July 1 to August 9	*Los Angeles June 29 to August 7*
Total distance steamed in knots	9,184	9,151
Average knots per hour throughout voyage	10.39	10.24
Average revolutions per minute	85.75	65.94
Average vacuum	28.61	26.72
Steaming time loaded and light	36 days 16 hrs. 50 min.	37 days 5 hrs. 6 min.
Fuel used steaming loaded and light, barrels	6,875	8,293
Fuel used per knot steaming, barrels	.748	.906
Fuel used in port pumping, barrels	107	186
Fuel used steaming and in port, barrels	6,982	8,479
Fuel used steaming and in port per knot, barrels	.760	.926
Cargo discharged, barrels	71,791.13	71,007
Time discharging	31 hrs.	56 hrs. 17 min.
Average barrels per hour discharged	2,315.84	1,261

	Per cent less	*Per cent greater*
Percentage less or greater fuel used steaming	17.09	20.6
Percentage less or greater fuel used in port	42.47	73.8
Percentage less or greater time in port discharging	44.92	81.5
Percentage less or greater fuel per knot steaming	17.43	21.13
Percentage less or greater fuel per knot steaming and in port	17.92	21.84

	Per cent greater	*Per cent less*
Percentage greater or less barrels pumped per hour	83.65	45.54

DISCUSSION.

THE CHAIRMAN:—Is there any discussion on this paper entitled "Electric Pumping Equipment and Notes of Interest on the Union Oil Company of California's Tank Steamer La Brea?" While the author is not present and his paper has been laid before you without reading, advance copies of it were furnished to those who took enough interest in the subject to ask for them. They are the ones who presumably will care to discuss the paper, and if any one has anything of interest to add or criticisms to make, now is his time. Let him stand up and come to the front and make them. This is not intended to deter live criticism by any means. In fact, we would be glad to encourage it, provided each man does not take more than his share of the time.

As the author is not present, and no one desires to discuss the paper, we will extend our thanks to Mr. Frear for the presentation of the paper, and pass to the next and final paper on our program, No. 17, entitled "The Commercial Gyroscopic Compass," by Mr. Elmer A. Sperry.

Mr. Elmer A. Sperry, *Member:*—Mr. Chairman and gentlemen, I do not think I need to take very much of your time. In speaking to our president, Mr. Taylor, about the paper, he suggested that I should take the time available for the presentation of the paper to tell you what makes a gyro-compass point north, and as it will only take two or three minutes to do that, I will proceed.

THE COMMERCIAL GYROSCOPIC COMPASS.

By Elmer A. Sperry, Esq., Member.

[Read at the twenty-fourth general meeting of the Society of Naval Architects and Marine Engineers, held in New York, November 16 and 17, 1916.]

The writer much appreciates the honor accorded him of making through the medium of the Annals of this Society the first public announcement of a new navigational instrument of precision, adapted to the merchant marine and also to the secondary fleets of our navies.

With the advent of the gyro-compass for navigational purposes, there was introduced for the first time an instrument of precision whereby courses could be laid with great accuracy, and dead reckoning computed with an exactitude theretofore impossible. The following illustrates the practical effect of this accuracy upon the navigation of our own navy. After the third compass had been installed on our battleships some years ago, the Bureau of Navigation called the writer's attention to a significant fact, namely, that it had been universally reported that "currents" had disappeared. To the writer, whose life work had been more or less intimately connected with electric currents, none other occurred to him, and he was accordingly mystified. However, this announcement really had far-reaching significance, inasmuch as it seems that "currents" are the scapegoat upon which the delinquencies of the magnetic compass and the faulty calculations due thereto had for years been fastened. This statement, therefore, was tantamount to the announcement that at last a compass had been found which could be relied upon as being true to the geographical meridian.

There have been constructed here in New York and installed by our engineers in various navies of the world about 600 gyroscopic navigational equipments, with their repeaters and other instruments and adjuncts. The major portion has been installed in the American, English, French, Italian and Russian navies. So far as known, the British Admiralty have the largest number of equipments in service at the present time, although other nations, including Japan, are installing the compasses rapidly. Considering the size of the navy, the largest number of compasses, strange to say, is employed probably by Denmark, although Spain may be considered a close second.

Perplexing and fitful are the disturbances to which the magnetic compass falls heir in increasing ratio as ships represent larger and larger masses of steel, and as cargoes contain steel and iron to an increasingly greater extent. It has been known for years that when a cargo consisting of a large steel component, such as ordnance, shifts even very slightly, all the magnetic compasses are at once disturbed. Steel cargoes, or parts that at some time in their history have been han-

dled by electric lifting magnets, usually retain more or less magnetism and strongly influence the ship's compasses. A cargo of iron ore, some of which may be magnetic, often induces strong disturbances.

It may not be generally known, but a perfectly innocent copper cable is one of the greatest enemies of the magnetic compass; for instance, in a submarine, where we have three thousand amperes direct current conducted by such a cable, the magnetic field set up will disturb a compass located at a remote point. One officer recently stated that it would disturb a compass in a "ten-acre lot," but it is evident that in the confines of a submarine it is impossible to get the compass at any such remote distance. The compass under the influence of this field often turns through 180°, and its magnetic conditions are frequently so changed that it never fully returns after the current has been cut off.

Again, repairs to the ship's hull, or alterations in the bulkheads invariably affect the ship's magnetic moments, as is also the case when the ship is struck or jarred strongly, so that frequently a complete readjustment of the ship's magnetic compasses is necessary. On the Great Lakes, as well as at other points of the globe, numerous local magnetic disturbances exist, which often throw the mariner off his course and probably serve to explain some of the serious accidents that occur, especially in fog, when observation is not feasible.

Another difficulty with the magnetic compass is that without warning it may suddenly revert to any one of its well-known vagaries, at a time when the ship is out of sight of bearings and observation is impossible, as in fog. This may be brought about even by an internal accident, jarring of the ship, or change of temperature. On one occasion the firing up of an additional bank of boilers and the heating up of a stack, though located quite remotely from the compass, without warning caused a fourteen degree deviation. This was discovered only just in time to avert disaster.

The electrical difficulty cited is true in degree of all direct-current wiring of all ships and yachts, but the electrical conditions and the electrical circuits do not in the slightest influence the gyro-compass. In the make-up of this compass the supports are all mechanical and no mercury or similar liquid is required.

The compass incorporates as an essential feature an indicator of its true meridional bearing. What a boon it would be to the magnetic compass if it could be supplied with an indicator, a glance at which would show at once whether the compass was giving a bearing that was true or false; in other words, whether it could be depended upon or not.

All of our gyro-compasses are supplied with just such a device, namely, an independent indicator that shows whether or not the compass is on the meridian. This has been found to be of great value in operation under service conditions, and to fulfill another important purpose—namely, that of aiding in quickly placing the compass upon the meridian by hand, which obviates the waiting for its automatically finding the meridian through its natural settling oscillations after starting.

The magnetic meridians themselves are so variable, often lying at such large angles with the true meridian, that constant vigilance is required to use them at all. In fact, the north magnetic pole itself is some twelve hundred miles distant from the geographic pole, and is known to be constantly shifting its position.

In addition to these difficulties, we have operating troubles with the magnetic compass, which aggravate the case materially. Among these may be cited the heeling error, which is a constant source of wonder to those unfamiliar with the large angle of motion through which the needle persists in swinging, perfectly synchronous with the roll of the ship. On torpedo-boat destroyers this heeling error amounts to a wide angle of swing when the boats are in the act of rolling, as they sometimes are for days, it being nothing short of a miracle that our good officers succeed in performing with such an inadequate instrument as the magnetic compass the wonderful feats of navigation recorded.

This heeling error is still greater in the case of aeroplanes. When the use of a magnetic compass is undertaken upon aeroplanes, if the machine is put into even a mild case of banking, in which it persists for an appreciable period, the heeling error of the compass is found to be of such magnitude as to render the compass useless. In some instances it will amount to 360°, or around the entire circle, giving no clue whatever to the aviator as to the true azimuth or where to stop on the turn and straighten out into the tangent. Thus the compass fails him utterly at just the critical time when it is most needed. After the tangent is persisted in for a sufficiently long time for the compass to settle, then and then only does it again become useful.

Moreover, the lag or tardiness of action of the magnetic compass is a serious drawback to the accuracy of the steering. The tendency of the helmsman is to follow this deviation longer than he would if the compass were dead-beat and without the feature of lag, which gives a constant tendency to a sinuous course and contributes materially in several ways to the lowering of navigational efficiency and fuel economy. It has been established repeatedly that with the gyro-compass, where the lag has been entirely eliminated, so that it does not extend to even one-hundredth of a second, ships are enabled to lay a very much closer course and materially less helm is used, with the consequence that a considerable gain in navigational efficiency is effected, both in speed and fuel economy.

With the gyro-compass there is never any necessity for swinging the ship. It has been found in some of the navies that the gyro-compass, giving the exact geographical meridian as it does, serves every purpose for a base line; and that such magnetic compasses as are used upon the ship may receive their adjustment from the gyro-compass when the ship is found upon different headings. There have been some very interesting accounts of the value of time thus saved—for instance, the Invincible on being called from England to the Falkland Islands, reached its destination just in the nick of time, with the well-known results, only because it did not stop to swing ship for adjustment of the magnetic compasses, which was im-

peratively due on leaving dock under the conditions in this instance, the magnetic compasses being adjusted from the gyro-compass on the way south.

Within the last four years a large mass of data has been accumulated, from daily and other records and logs, of the performance of the gyro-compasses upon practically all of the "Seven Seas." These records agree in demonstrating that in the gyro-compass we have an instrument entirely free from all of the difficulties and disturbances to which the magnetic compass is subject.

One word as to the theory of the gyroscopic compass: The principle is well illustrated by the statement of one of the admirals of the navy, to the effect that the writer was the only man of his knowledge who would "lose his job if the earth should happen to stop." It is a fact that the field of force utilized and upon which the new navigational instrument depends for its directive power is the actual rotation of the earth—the steady easterly advance of a point on the earth's surface. This angular motion, although it occurs about an axis some 4,000 miles distant, through a well-known gyroscopic phenomenon, compels the gyro wheel to set its spinning axis parallel with the axis of the earth. The earth's rotational force is so impressed upon the gyro as to cause this phenomenon to take place with the greatest exactness, so that it may be employed as a navigational compass of high precision. The phenomenon being a terrestrial one, the pointing is upon the true geographic meridian, which is identical with that utilized in navigation; therefore, when the compass is properly organized, no deviations or variations exist to complicate its use.

The reason for the high precision of the gyro-compass lies in the fact that, in addition to its true meridional pointing, its tenacity of purpose or directive power is many times that of the magnetic compass. Our battle compass gives 291 times the directive power of a 7½-inch navy standard magnetic compass (see Commander T. A. Lyon's [U. S. N.] "Magnetic Moment of the Compass"). This estimate is for the compass in an open field, but down in the interior of a ship the gyro-compass, surrounded entirely by steel (as is the case with practically all master compasses), has a directive power still very much greater than that of the magnetic compass in the same position.

The same is true with the new commercial compass. Its directive power is about one hundred and fifty times that of the same standard navy magnetic compass, in the positions occupied in both naval ships and those of the merchant marine.

In the gyro-compass equipments using repeaters, a secondary transmission system is employed. This comprises a transmitter, operated by and forming part of the master compass, and various forms of repeating instruments, controlled by the transmitter, but located at distant points about the ship. The transmitter, shown in Fig. 5, Plate 125, is power driven by the compass and is also connected with the automatic correction device in such a manner that only corrected readings of the master compass are transmitted to the repeaters, which thus read in true bearing on the meridian.

Repeaters, which indicate the true headings of the master compass, may be

located wherever desired on the ship. Various other devices, such as azimuth indicators, recorders, automatic latitude instruments, ordnance appliances, automatic steering mechanism, etc., may be operated from the same circuits that supply the repeaters.

All repeating instruments are positively driven by especially designed step-by-step motors, which have no moving contacts in circuit. These instruments follow the movements of the master compass with a maximum error of about one-twelfth degree and a lag of about one-hundredth of a second. Less than 10 watts of energy are consumed for each instrument, yet the card is driven with as high a torque as 10,000 gm. cms., which abundantly insures the instruments against derangement from shock of gunfire. This has been verified by tests upon ships of the U. S. Navy under conditions of shock resulting from repeated salvos of ten 12-inch or 14-inch guns, which caused no derangement of the compass or repeaters.

Not only is there an entire absence of variation and deviation in the Sperry gyro-compass, but extended experience at sea shows that there is no heeling error even in the heaviest rolling, this being true for all headings.

The portable repeater is sometimes very useful, especially in submerged torpedo fire. It is illustrated in Fig. 6, Plate 125.

The battle compass is designed to develop a high directive power, because its responsibilities are very great—that is, it has to carry along with it a large number of auxiliary instruments outside of the regular quota of repeaters. For instance, the gyro-compasses that are being furnished to the Admiralty have no less than fifteen repeater outlets. For the secondary ships of the navy and for the merchant service, no such demand is made upon the master compass, and it may therefore be made smaller, so as to involve considerably less equipment, without having its accuracy impaired within the limits of observation, and consequently can be produced at a lower cost.

Such a compass, however, is more difficult to construct in some particulars, because it must be entirely free from disturbances resulting from far rougher treatment than is the case with the battle compass. To accomplish this and still keep the compass as small as possible, and to prevent these more vigorous disturbances from decreasing its accuracy, the wheel has been divided into two smaller wheels, and a number of other radical changes have been introduced into the structure, with the result that a gyro-compass has been produced which is found under service conditions to fulfill all of the most difficult requirements. For instance, one item in the official trials was to run the nose of a destroyer into the gale, holding a course for some hours, which produced persistent rolling of the vessel through 60° of arc, with the result that the gyro-compass showed not the slightest tendency to disturbance or departure from the meridian—it, however, being about the only thing on the boat that did not lose its equilibrium. This rolling test was only one of a number of severe conditions to which the compass was subjected, but with practically no effect upon its accuracy, the entire test being under seal and no one being permitted to touch the compass day or night through long periods.

The new compass is smaller and lighter than the battle gyro-compass, and is being developed in a still smaller form for use on aeroplanes and small yachts. As built at present, it weighs only about 50 pounds, exclusive of the binnacle in which it is mounted, the complete weight with the binnacle being only about 225 pounds. The smaller size will weigh only about 40 pounds when the aeroplane mounting is used, there being no binnacle. The overall diameter of the compass with the binnacle is only about 16 inches, and the weight about 100 pounds.

Due to the small size of the wheels (the wheels used on the destroyer type are only 5 inches in diameter), the time required to bring the compass up to speed from rest is only about five minutes.

If the ship upon which the compass is mounted is to be tied up at dock for some length of time, the switch may be opened and the compass allowed to come to rest; then if the switch is again closed about fifteen minutes before the ship is to sail, the compass will come up to speed and immediately settle upon the meridian. Of course, it is desirable to start up the compass earlier in order to give time for it to settle completely, but in some cases it may be a great advantage to be able to use it almost immediately after it has been started up. During one of the earlier sea trials, the supply switch was accidentally opened in the engine room and the compass had come to rest before this was noticed; but as the ship was on a straight course, the switch was simply thrown in, whereupon the compass came up to speed, and the first observation made showed it to be almost exactly on the meridian. The compass may also be placed on the meridian by hand before starting, in case the ship is at rest, and it will then come up to speed and be found to be on or very near the meridian without any further setting.

The compass is designed with a view to reducing to a minimum any attention that may be required, making it unnecessary for the ship to have a man specially trained to care for it. For instance, it might easily be started up in New York and would not need inspection again until the ship reached Liverpool.

In this connection it may not be out of place to state that in addition to guaranteeing each compass, the manufacturers have trained compass experts in nearly all of the principal ports of Europe, each with full equipments, spare parts, etc., some seventeen operating out of the London office alone. It is the duty of these engineers to instruct officers and men as to the care and operation of the compass, and also to see to it that every compass coming into their ports is giving perfectly satisfactory service.

In trial, and in fact all of the earlier voyages made by new steel ships, the gyro-compass should be employed, even if it must be under rental, because of the large changes that are constantly going on in the magnetic moments of new ships. When a new ship is constructed on her ways, the driving of the myriad of rivets tends to magnetize the entire structure very permanently and to a high degree. Lord Pirrie told the writer that it cost him the equivalent of $2,800 to take the Olympic sufficiently out to sea to enable her to be turned prior to receiving her engines and finish, solely on account of aiding the magnetic compasses in their

behavior on the first few voyages. All such maneuvers could be easily avoided by employing the new compass, which is totally unaffected by any magnetic conditions whatever, and which at the same time may be used to adjust all magnetic compasses as often as desired.

Three standard compass equipments are supplied, the simplest of which is shown in Fig. 1, Plate 123, and the most complete in Fig. 2, Plate 123. As will be seen, the simpler equipment consists only of the master compass, motor generator, and a very simple switch panel, while the larger equipment contains in addition a pelorus stand, storage battery, two repeater compasses, and a larger switchboard, one panel of which is to care for the repeater compasses. These equipments are being installed on the secondary naval ships and the larger ships of the merchant marine.

Another equipment is also provided in which the pelorus stand is omitted and a switchboard intermediate between the two illustrated is supplied. The entire master compass operates on alternating current, and in the case of the equipment where no repeater compasses are used, the motor generator simply converts a slight amount of the ship's supply of direct current into alternating current of the proper voltage and frequency. The generator operates automatically. The repeater compasses, however, operate on a low voltage direct current, and the motor generators for these equipments are extended on one end and serve also to generate the slight amount of low voltage direct current required. In these equipments a storage battery is also provided, and arrangements are made so that, in case of failure of the ship's supply, the entire compass equipment will be automatically transferred to the storage battery, which has sufficient capacity to carry the entire equipment independently for a period of two or three hours.

The binnacle of the master compass is provided with lock and key to prevent meddling by unauthorized persons. In order to make the frequent removal of cover or bowl unnecessary, and to make it possible to inspect the compass through the glass cover, a lamp is provided in the pedestal for the illumination of the inside of the binnacle.

Figure 3, Plate 124, gives a sectional view of the binnacle and portion of the compass showing the internal arrangement and heavy glass cover.

Figure 4, Plate 124, gives a view of the navy type of gyro-compass card showing binnacle.

Either of the two types of repeater compasses shown in Figs. 7 and 8, Plates 125 and 126, may be used, each being supplied with several types of mounting. As far as the repeaters themselves are concerned, the principal difference in the two types is in the size of the card, the mechanism which drives the card being the same. In either type the part of the card that carries the degree marks is made of translucent material and is illuminated by means of a lamp contained within the repeater casing, which may be turned on or off, or, what is most important for the helmsman, may be dimmed to any degree by means of a dimmer, which is weatherproof and forms a part of the equipment.

The gyro-compass with its great directive power and repeater system affords the unique opportunity for operating still other devices which have been found of great service on shipboard. Not only can the gyro-compass actuate the automatic helmsman, which holds the ship with great precision and minimum helm, but it may also operate a recorder, which makes an automatic record of every change of heading, however minute, recording the exact moment of such change, thus giving a continuous and accurate record of the heading of the ship. This instrument is incidentally useful in obtaining the characteristics of different helmsmen, and its records are of the greatest value to the navigator, especially when observations are impossible—navigating by dead reckoning. This new instrument is very simple, consisting merely of a repeater compass with an enlarged removable dial upon which the record is made by a recording pen operated by a small clinometer seen above the dial. This instrument is shown in Fig. 9, Plate 126.

Figure 10, Plate 127, shows the comparison between the larger battle gyro-compass and the new destroyer or commercial compass, the latter being to the right.

From service tests already had and all indications, the new commercial compass has justified the very considerable labor and expense involved in its development.

The acknowledgment of the author is due to Mr. H. L. Tanner, who has shown wonderful persistence and ingenuity in overcoming the difficulties attendant on developing the new gyro-compass in its simplified form, through work extending over a series of years.

DISCUSSION.

The Chairman:—Your applause shows your appreciation of Mr. Sperry's address and his paper. Does any one desire to ask him any questions? I doubt if any one has any criticism to offer. Some may want to ask him questions. Possibly the naval officers present may have some observations to make. If not, this is the last paper to be presented, and completes our program for the day. I think on the whole we have had a very successful meeting.

It has been a source of regret that the shipbuilding interests usually represented here by so many of their number have been rather sparsely represented at this meeting and that only a few have been present. Of course, you who have read the papers know the reason; you know that there is a conference in Washington which has kept so many of them away from the meeting, which is a source of great regret to many of us.

I desire to remind you of the banquet to-night. Those who have not received tickets should apply to the Secretary or his assistant. There is every prospect that the banquet will be the greatest one, so far as attendance goes, that the Society has ever held. I understand

that more than four hundred have arranged to be in attendance. It will be held in the big ballroom of the Waldorf-Astoria, and seven o'clock is the hour for assembling.

Unless there is some further business to come before the meeting we will now stand adjourned.

Adjourned.

Deaths, 1916

DARWIN ALMY

MEMBER

Darwin Almy was born in Tiverton, R. I., on February 28, 1848. He attended the local schools in Tiverton until about sixteen years of age and then took up work on his father's farm until the death of the latter in 1868. Afterwards, he became interested in menhaden fishing and was master of one of the first fishing steamers out of Tiverton.

In 1874 he went to Providence and formed a partnership for the manufacture of jewelry, which was abandoned about two years later. After this he returned to the fishing business.

In 1878 he entered the employ of the Herreshoff Manufacturing Company at Bristol, R. I. He had charge of the boiler department and had the advantage of taking part in numerous trial trips of fast steam yachts. During the first part of this time the government conducted there a series of experiments under Admiral Zellar and Admiral Isherwood on engines and boilers, and through this association he became very much interested in steam engineering.

In 1890 he took out his first patents on the boiler which bears his name and organized the Almy Water-Tube Boiler Company, of which he was the head until his death.

He was a member of the American Society of Mechanical Engineers, the American Society of Naval Engineers, the Society of Naval Architects and Marine Engineers, Providence Association of Mechanical Engineers, Chamber of Commerce of Providence, Central Club of Providence, Bristol Yacht Club and Rhode Island Yacht Club.

He died in Providence on March 9, 1916.

CAPTAIN WILLIAM HENRY JAQUES

LIFE MEMBER

William Henry Jaques was born in Philadelphia, Pa., December 24, 1848, and died November 22, 1916.

His education was received in the schools of New Jersey, and in September, 1863, he entered the United States Naval Academy as midshipman. Being graduated with honor in June, 1867, he went immediately into active service; was promoted to ensign on December 18, 1868, master on March 21, 1870, and lieutenant, March 21, 1871.

During his active service in the navy, Captain Jaques served on board the Constitution, Marblehead, Minnesota, Canandaigua, St. Louis, Quinnebaug, and the monitors Saugus and Manhattan, and at various times performed duties as aide to the President, Secretary of the Navy and Commandant of the New York Navy Yard.

He also had charge of various important scientific works:—1870–1874, assistant in the United States Coast Survey, in charge of triangulation, surveys, chart-making, deep-sea research and astronomical work; 1874–1878, assisted the New York Board of Education in technical education; in 1881–1882 was assistant inspector of ordnance; in 1883–1885 member and secretary of the United States Gun Foundry Board and member of the Board for the Improvement of the Washington Branch of the Potomac River; in 1886–1887 secretary to the Senate Committee on Ordnance and Warships.

Captain Jaques introduced into the United States the system of fluid compression and hydraulic forging of heavy masses of steel and was the inventor of many improvements in the manufacture of heavy ordnance and armor, notably the double-forging process of armor adopted by the United States, and was the leading exponent of the employment of nickel in steel. He was for some time associated with Capt. John Ericsson in the development of submarine artillery.

Captain Jaques resigned his commission in the navy, November, 1887, and accepted a position with the Bethlehem Iron Company (now the Bethlehem Steel Company) to superintend the design, construction and adaptation of machinery for the establishment there of ordnance and armor-plate works; and introduced there powerful hydraulic presses for the fluid compression and forging of large masses of steel. He continued as ordnance engineer of the Bethlehem Company until June 1, 1894, when, having successfully accomplished all the obligations involved in the enterprise he advised them to undertake and in the new industries developed thereby, he retired.

He then became associated with the eminent engineer and naval architect,

Mr. Horace See, and others in general engineering and consultation in connection with the manufacture and treatment of guns, armor, shafting and other war material, and especially with the fluid compression and hydraulic forging of steel and the best types of armor.

At the beginning of 1895, at the request of the Governor of New Jersey, he began the organization of a Naval Reserve for that state, and on February 27 of that year was commissioned captain. This command he held until January, 1898, when loss of health compelled him to resign.

The later developments of the Bethlehem Works are in a great measure due to Captain Jaques. During the period that the works were adapted for the manufacture of guns and armor they have executed the principal contracts issued by the United States Government for all descriptions of war material, including shields, conning-towers, machine parts, shafting, heavy forgings, and carbonized and nickel steel armor-plate.

It was no small matter to have borne so prominent a part in the installation and organization of the naval power of one of the greatest countries in the world; the natural result was that Captain Jaques became the recognized independent authority in the United States and Europe on the manufacture of guns and armor.

He was presented the Whitworth scholarship medal for his metallurgical work and was decorated by the Emperor of Japan with the Order of the Rising Sun for his valuable services to Japan previous to the Chinese War. He also received the formal thanks of the Peabody Academy of Science for his services in the Coast Survey in 1874; of the United States Lighthouse Board for valuable aid rendered in the reconnaissance of the Stratford Shoals in 1878; and of the United States Coast and Geodetic Survey for his examination of the New England Coast and tabulation of results accepted as guide for Massachusetts Bay.

Having done his full share in bringing the ordnance and armor of the United States to a high standard of excellence, he, in 1897, undertook the development of submarine torpedo-boats and accepted the presidency of the Holland Submarine Boat Company, greatly aiding in perfecting the Holland type. During his incumbency the mechanical control of submersion was perfected, which forms the vital character of the modern submarine.

Captain Jaques was the author of numerous books and monographs on heavy ordnance, armor, torpedoes, solar radiation, etc., and an authority on water engineering. He was one of the international jury on marine transportation and war material at the Columbian Exposition of 1893.

JAMES MINOR LINCOLN

MEMBER

At his home at Wareham, Mass., James Minor Lincoln of New York City died, after an illness of about two months, March 28, 1916, in his sixty-second year.

Mr. Lincoln was born at Lewisburg, Pa., on September 1, 1854, and lived in Cincinnati, Ohio, during the Civil War. His family then removed to Boston, Mass., where he went to public school, and then to New York City, where he attended the College of the City of New York in the class of 1874, but left after three years to enter the employ of the Pacific Mail Steamship Company.

He was purser of the S. S. Georgia of this line when it was wrecked in the Straits of Magellan. He returned to the United States via the West Coast of South America and Panama, where he inspected the railway and the canal route for the company. He then joined the Clyde Steamship Company as purchasing agent and later became in addition chief draughtsman and assistant engineer of the line. In 1895 he was obliged to resign because of ill health, after twenty-one years of faithful service.

Thereafter he devoted himself to genealogy and historical research and collected a large amount of information concerning Indian and Colonial matters around New York City and in southeastern Massachusetts. He published two books on family genealogy and historical papers, "The Lincoln Family and Branches, of Wareham, Massachusetts" and "The Papers of Captain Rufus Lincoln of Wareham, Massachusetts," and calculated a table for determining the pitch of screw propellers which he presented to the United States Navy Department, where it was used for a long time. He also helped to organize the Lincoln Memorial Committee composed of representative Americans and Englishmen who were erecting a memorial to Abraham Lincoln at Hingham, England, whence the family emigrated to America in 1637, when the European War began.

Mr. Lincoln was genealogist of the Lincoln Historical and Genealogical Association of Taunton, Mass., and of the Ludwig Historical Society of Lewisburg, Pa.; a charter member of the Empire State Society Sons of the American Revolution, a life member of the New York Historical Society, and of the Old Colony Historical Society of Massachusetts, and a member of the Society of Naval Architects and Marine Engineers and of the American Society of Naval Engineers.

On October 28, 1884, he married, at New York City, Josephine Vermilye Lott, who survives him.

WILLIAM NISH

MEMBER

Mr. Nish was born in Glasgow in 1849. After a good education in his native city, he began his apprenticeship to engineering with Messrs. McOnie, Harvey & Company, Glasgow, and finished the standard period with Messrs. Caldwell & Company. He was trained in pattern-making, fitting and other branches. Later he worked for some time in the Finnieston Marine Engineering Works of Messrs. D. & W. Henderson.

In 1872 he went to sea as fourth engineer in the Anchor Line and, after serving and qualifying through the several grades, was appointed chief engineer of the S. S. Scotia. He was chief successively in the Anchor Line steamers Sidonia, Europa, Anglia and the Ethiopia. In 1887 Mr. Nish was appointed assistant to the chief engineering superintendent of the Anchor Line. In 1889 he was appointed to be resident superintendent at New York. This position he held till his death, being deeply regretted by the principals and those associated with him in the service of the company on both sides of the Atlantic. For his abilities as an engineer, no less than for his sterling character and happy social nature, he was highly respected and widely popular.

Mr. Nish died in New York on September 15, 1916.

WILLIAM ALFRED PERRY

MEMBER

William Alfred Perry was born April 22, 1835, in Brooklyn, N. Y. He graduated from Columbia College, New York, Class of '55, and entered the firm of Henry R. Worthington in March, 1856. After thirteen years he became a partner and later vice-president of the company.

Mr. Perry was always interested in mechanical engineering, suggested improvements of value in the development of the Worthington pumping engine, and was instrumental in its introduction into foreign countries. The first propeller ferryboat with guards that ran in New York Bay was built under his direction by Percy Jones of Philadelphia. The boat was run as a ferryboat between Bay Ridge and New York.

Mr. Perry was also a director in the Union Ferry Company, belonged tc the University, Century and Engineer Clubs, and was a member of the Colonial Wars. He was a member of this Society from its inception. He died on February 16, 1916.

JAMES CHASE WALLACE

MEMBER

James C. Wallace was born in Cleveland on May 23, 1865, the son of the late Robert Wallace, a pioneer among shipbuilders. At the age of sixteen Mr. Wallace started to gain the knowledge which was to stand him in such great stead later in life by beginning a three-year machinist apprenticeship. In 1884 he entered the employ of the Globe Iron Works in successively the machine shops, the shipyard and the draughting room. When the iron steamer Onoko came out he sailed in her as assistant engineer. In 1887 he and his father organized the Cleveland Shipbuilding Company. In 1890 he had become assistant superintendent and three years later he was chosen vice-president and general manager. In 1893 Mr. Wallace effected the organization of the American Shipbuilding Company to take over the Cleveland Shipbuilding Company and he was retained as vice-president and general manager of the large organization. In 1904, before reaching his thirty-ninth year, he was chosen president to succeed A. B. Wolvin, and thus had worked his way up through every department of a shipbuilding industry. He was president of the American Shipbuilding Company for ten years and he was instrumental in shaping the type of construction from the small steel vessels to the giant steamers of 12,000 tons.

At the time of his death Mr. Wallace was a director in the American Shipbuilding Company, in the Pioneer, Kinney and Valley steamship companies, and in the American Board of Lloyd's Register of Shipping of London. He was a Member of this Society. He died on October 31, 1916.

RALPH D. WILLIAMS

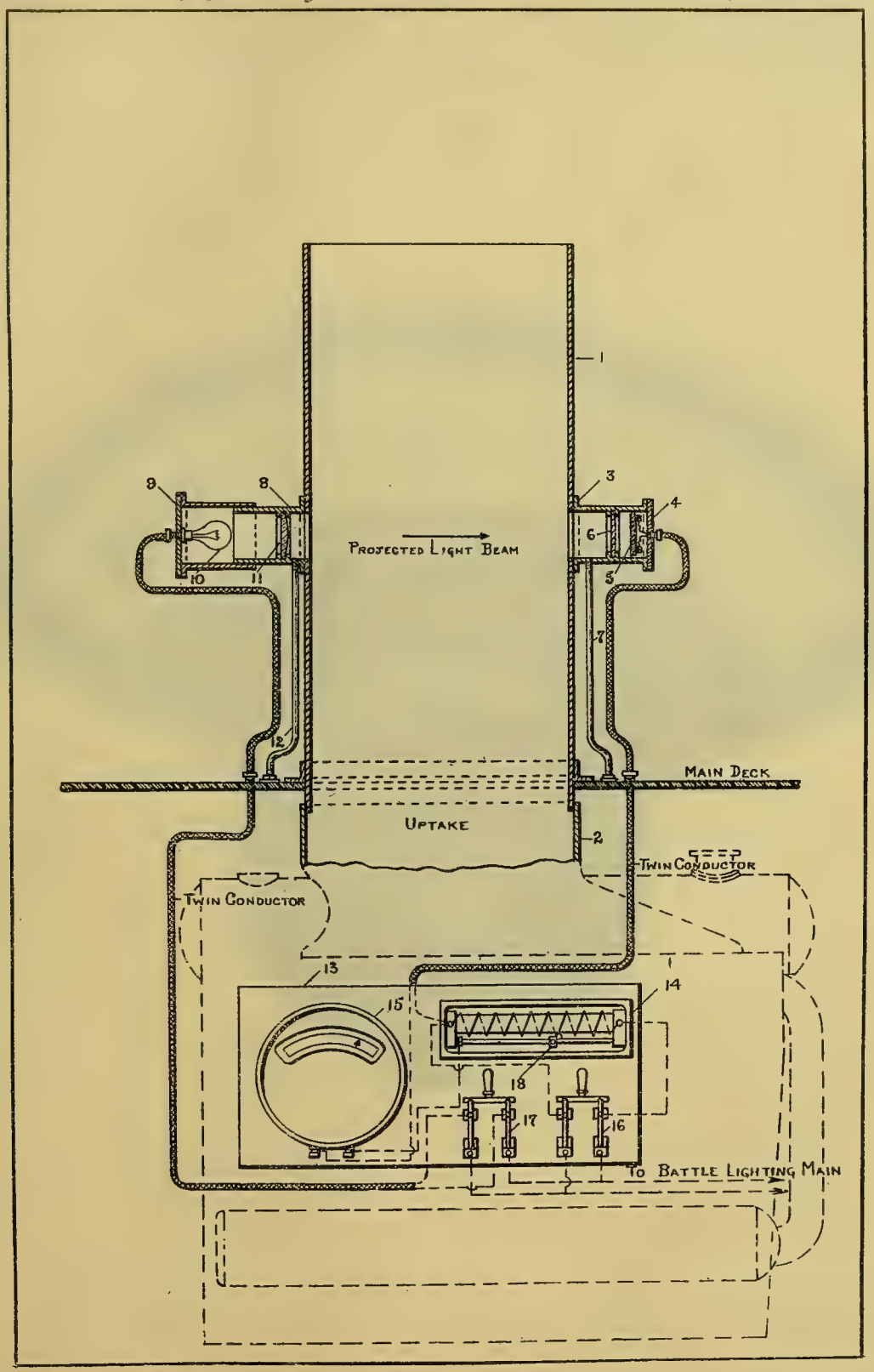
ASSOCIATE MEMBER

Ralph D. Williams was born near Nottingham, England, in 1868. He came to the United States and took up his residence in Cleveland, Ohio, when about ten years old. At an early age he became a reporter on the *Cleveland Plain Dealer,* where he rose to the managing editorship before ceasing service with that paper. Thereafter he became editor of the *Marine Review,* in which capacity he served for fifteen years. His health failing he relinquished active

work and confined himself to the statistical work of the Lake Carriers' Association, to the preparation of *The Bulletin,* and to the working out of details in connection with the schools of the Association.

Mr. Williams gave years of thought to the Great Lakes trade and his book, "The Hon. Peter White," was the crowning effort of a life which he largely gave to a subject he loved. He had a wonderful and invaluable fund of knowledge regarding lake traffic, shipbuilding, the production and history of ore, coal and other commodities. His loyalty and integrity were outstanding attributes and his gentleness endeared him to his friends. He died on August 16, 1916.

To illustrate paper on "New Method of Indicating the Density of Smoke as Installed on the U. S. S. Conyngham," by Rear Admiral R. T. Hall, U. S. N., Member.



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To illustrate paper on "New Method of Indicating the Density of Smoke as Installed on the U. S. S. Conyngham," by Rear Admiral R. T. Hall, U. S. N., Member.

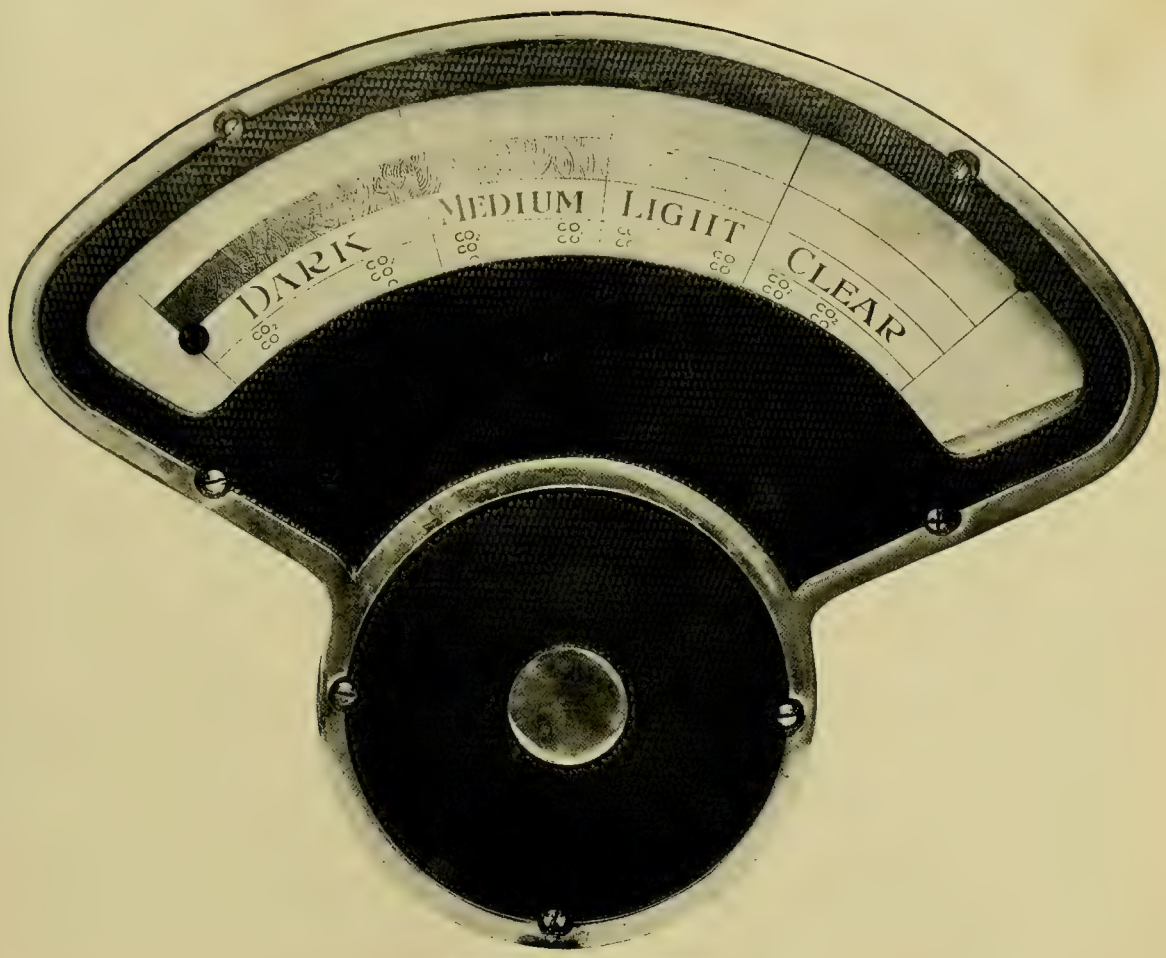


Fig. 2.—Indicating Meter.

MARINE
BIOLOGICAL
LABORATORY
LIBRARY
WOODS HOLE

To illustrate paper on "New Method of Indicating the Density of Smoke as Installed on the U. S. S. Conyngham," by Rear Admiral R. T. Hall, U. S. N., Member.

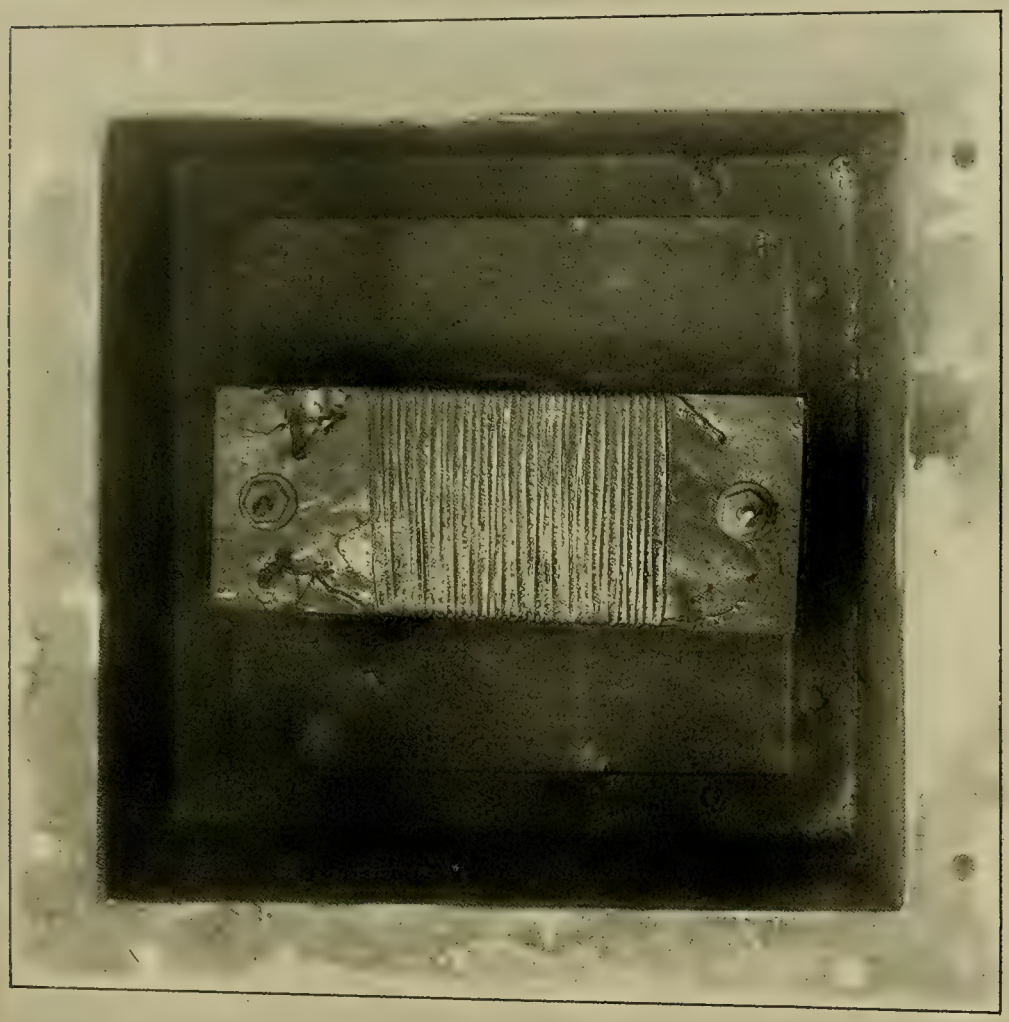


Fig. 3.—Selenium Plate.

To illustrate paper on "Salvage Equipment Used in Raising Submarine F-4," by Naval Constructor J. A. Furer, U. S. N., Member.

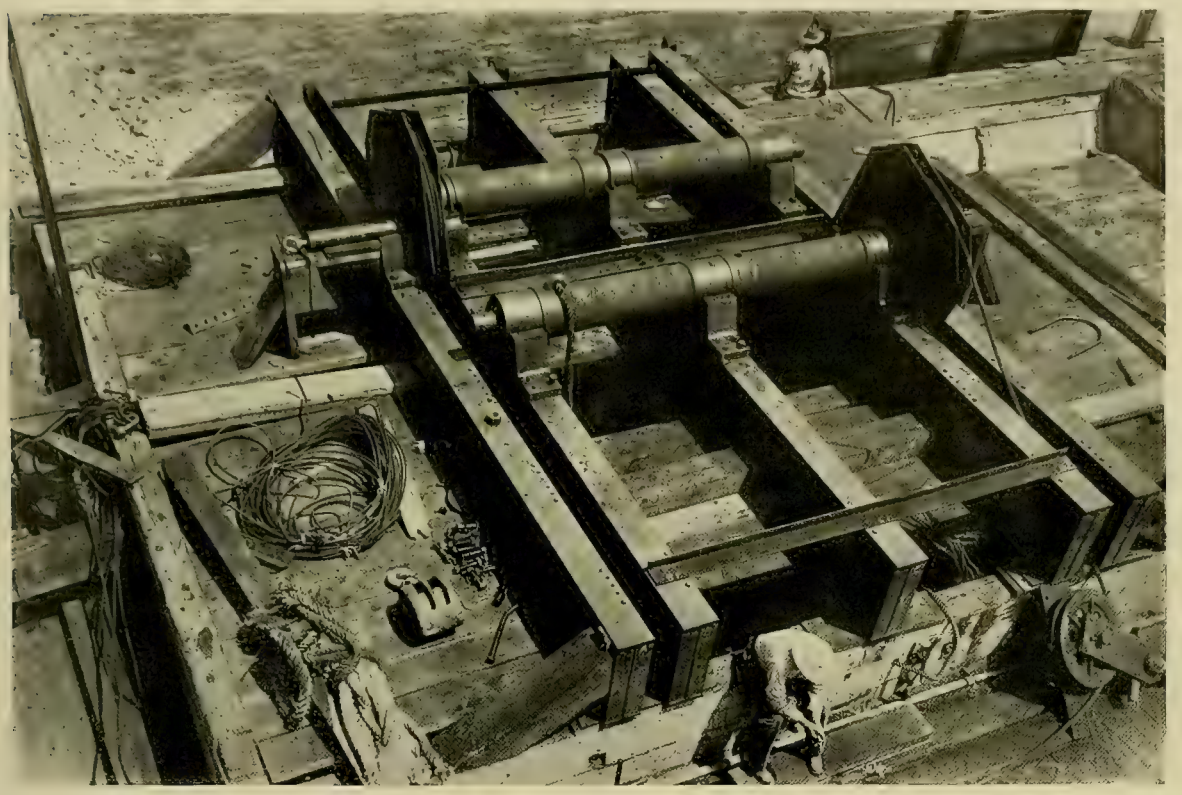


Fig. 1.—Windlass Foundations and Windlasses in Place.

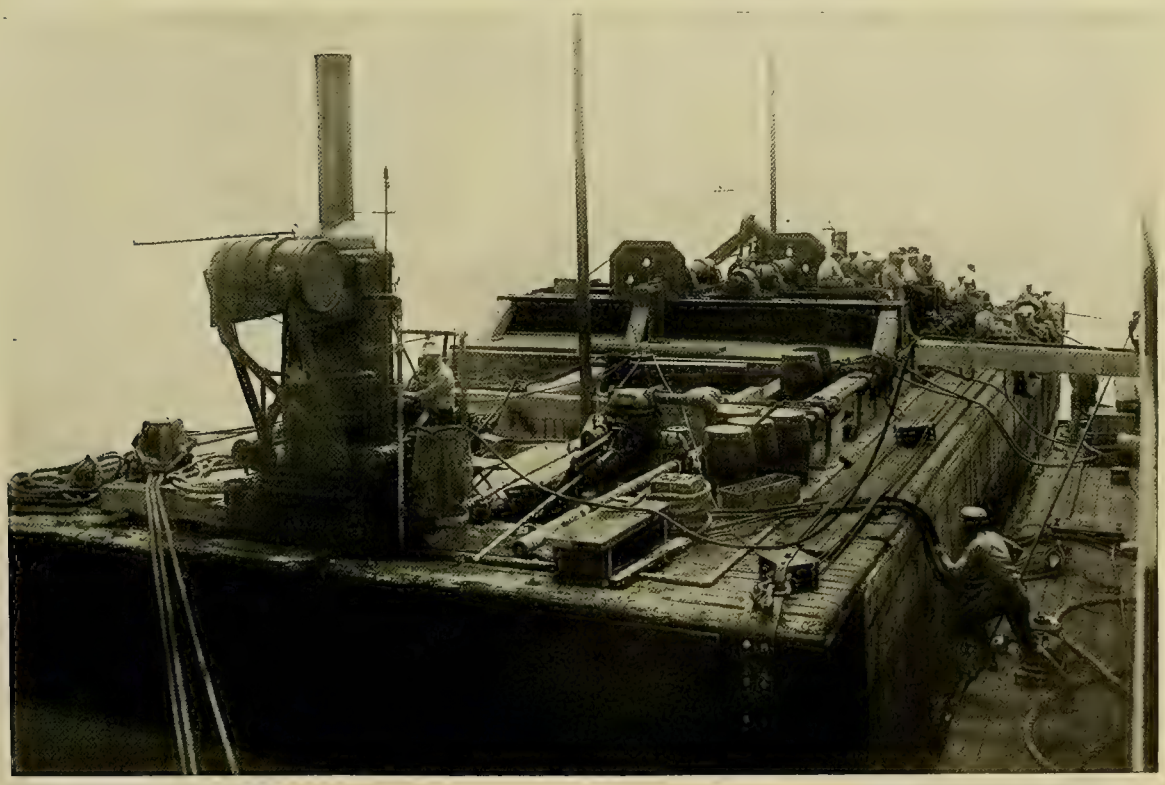


Fig. 2.—End View of Scow, Showing Running Gear.

To illustrate paper on "Salvage Equipment Used in Raising Submarine F-4," by Naval Constructor J. A. Furer, U. S. N., Member.

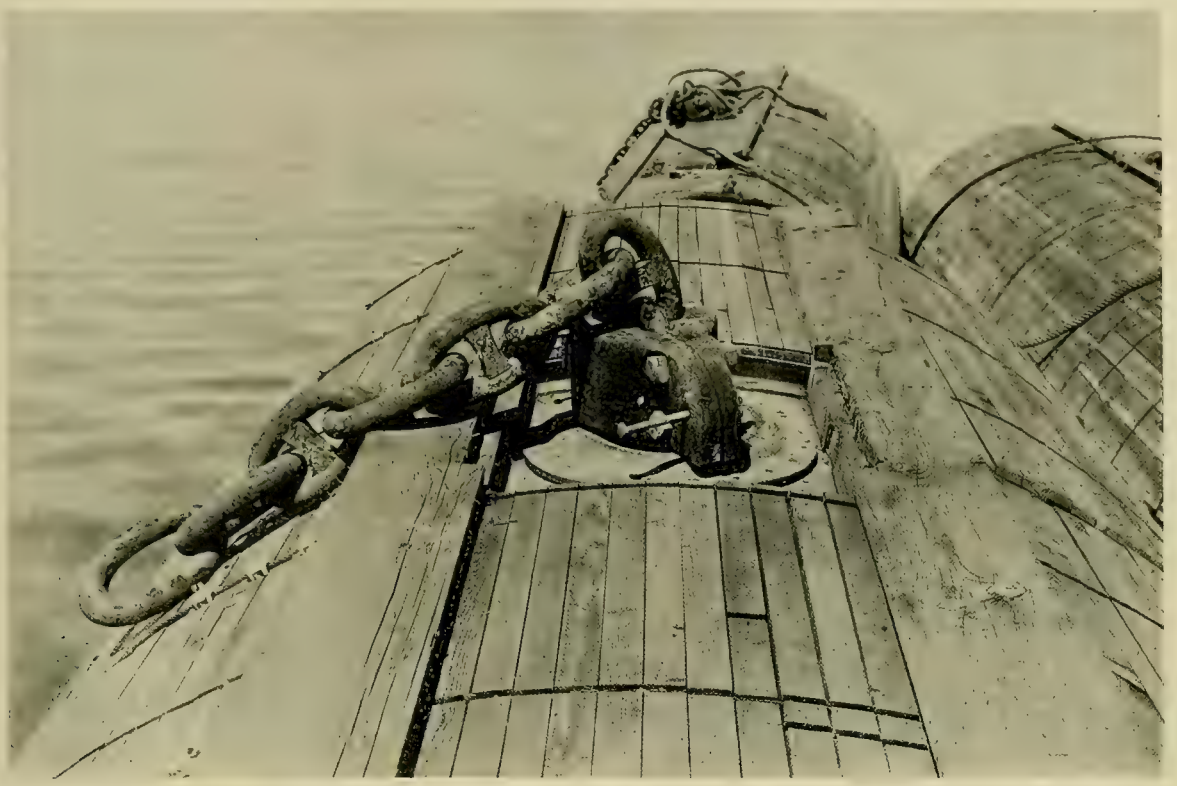


Fig. 3.—Method of Securing Chain by Means of Clamp.

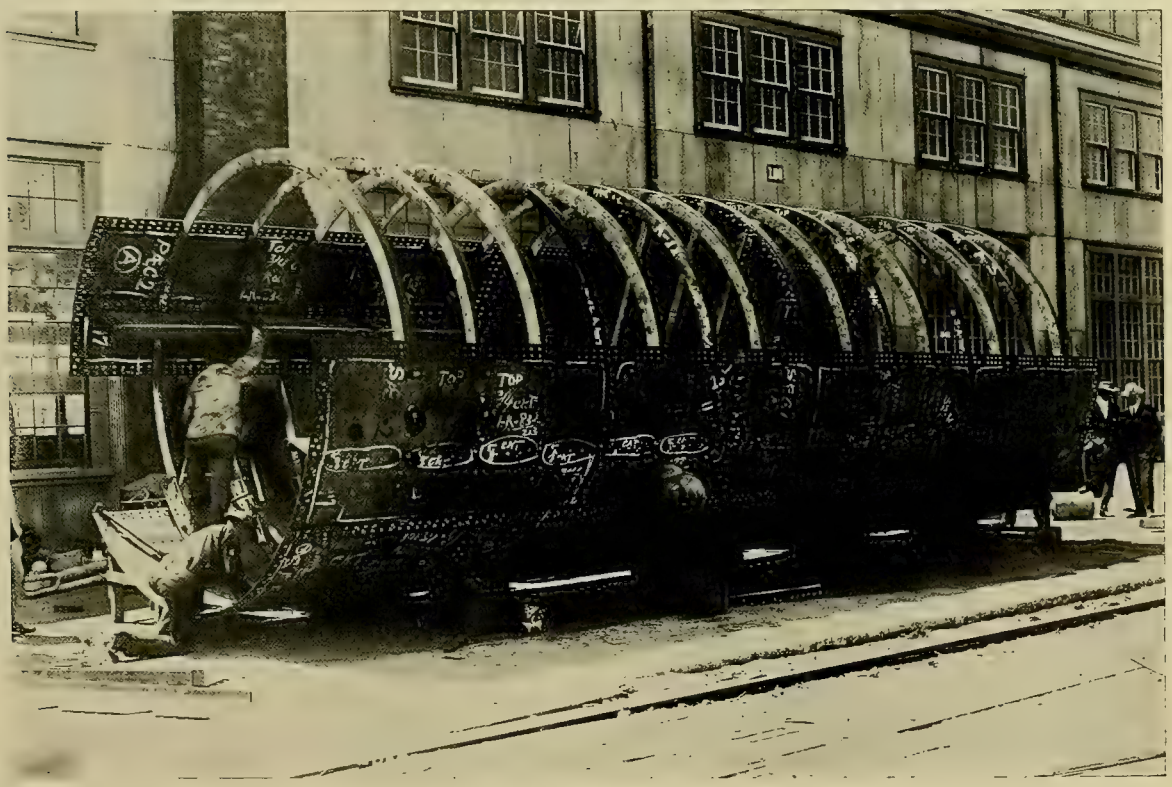


Fig. 4.—Pontoons Under Construction, Showing Middle Bulkhead.

To illustrate paper on "Salvage Equipment Used in Raising Submarine F-4," by Naval Constructor J. A. Furer, U. S. N., Member.

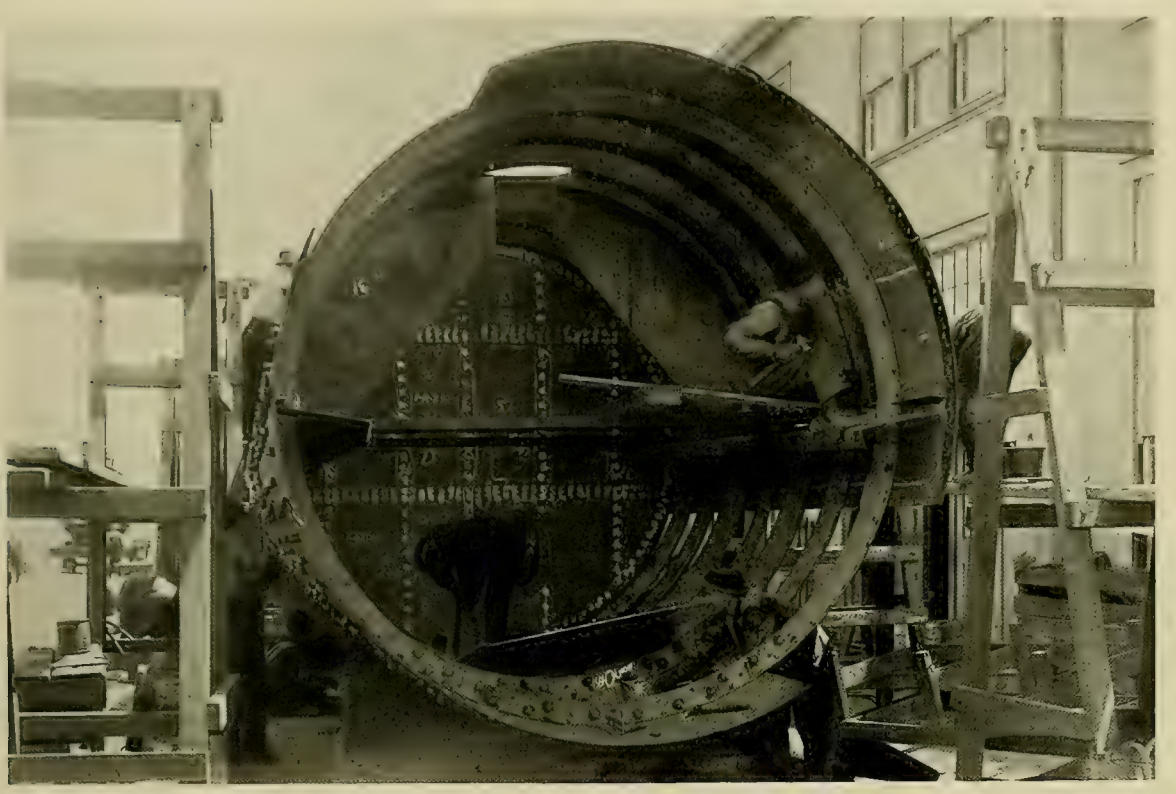


Fig. 5.—Pontoons Under Construction, Web Frame in Wake of Hawse Pipe.

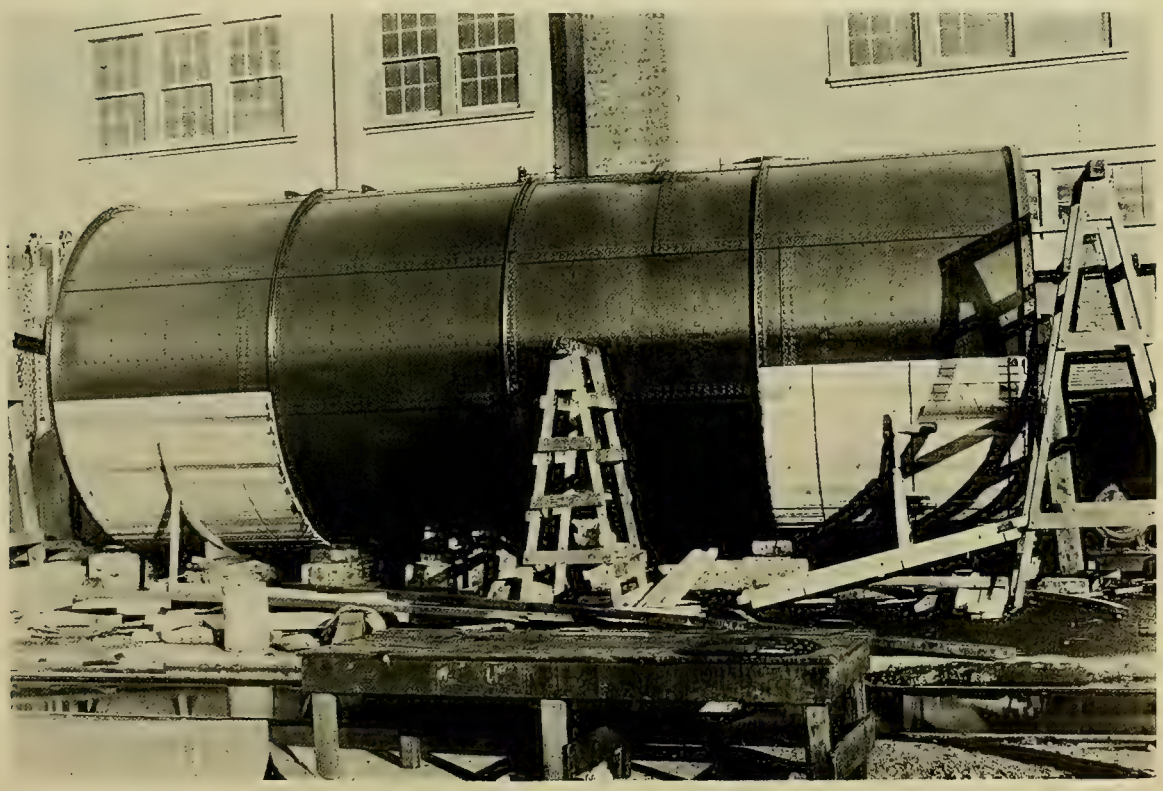


Fig. 6.—Method of Applying Wood Sheathing to Pontoons.

To illustrate paper on "Salvage Equipment Used in Raising Submarine F-4," by Naval Constructor J. A. Furer, U. S. N., Member.

Fig. 7.—Completed Salvage Pontoon Except for Wood Sheathing.

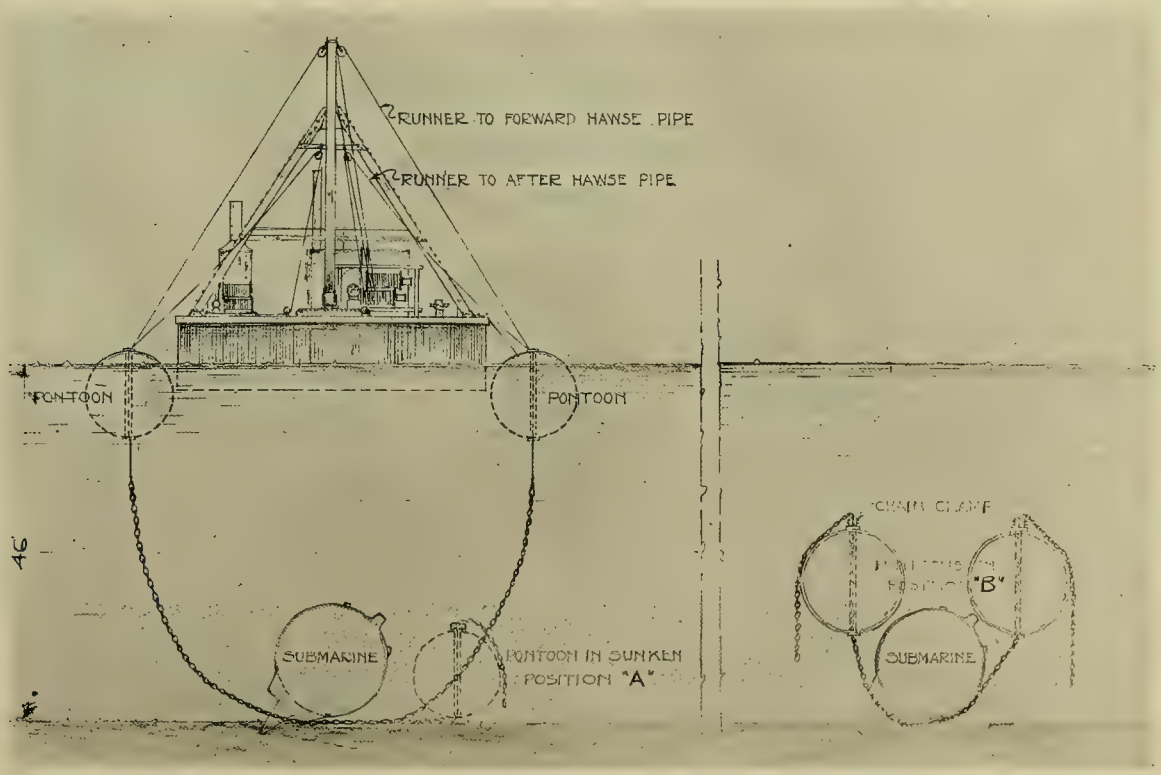


Fig. 8.—Method Used in Lowering and Securing the Pontoons.

To illustrate paper on "Salvage Equipment Used in Raising Submarine F-4," by Naval Constructor J. A. Furer, U. S. N., Member.

Fig. 9.—Pontoon Ready for Sinking with Chain Clamps in Place on Top of Hawse Pipes.

Fig. 10.—Torpedo Flasks Installed on Coal Barge and 7-Inch Pipe Manifold.

To illustrate paper on "Salvage Equipment Used in Raising Submarine F-4," by Naval Constructor J. A. Furer, U. S. N., Member.

Fig. 11.—Valve Manifold and Hose Leads to Submerged Pontoons.

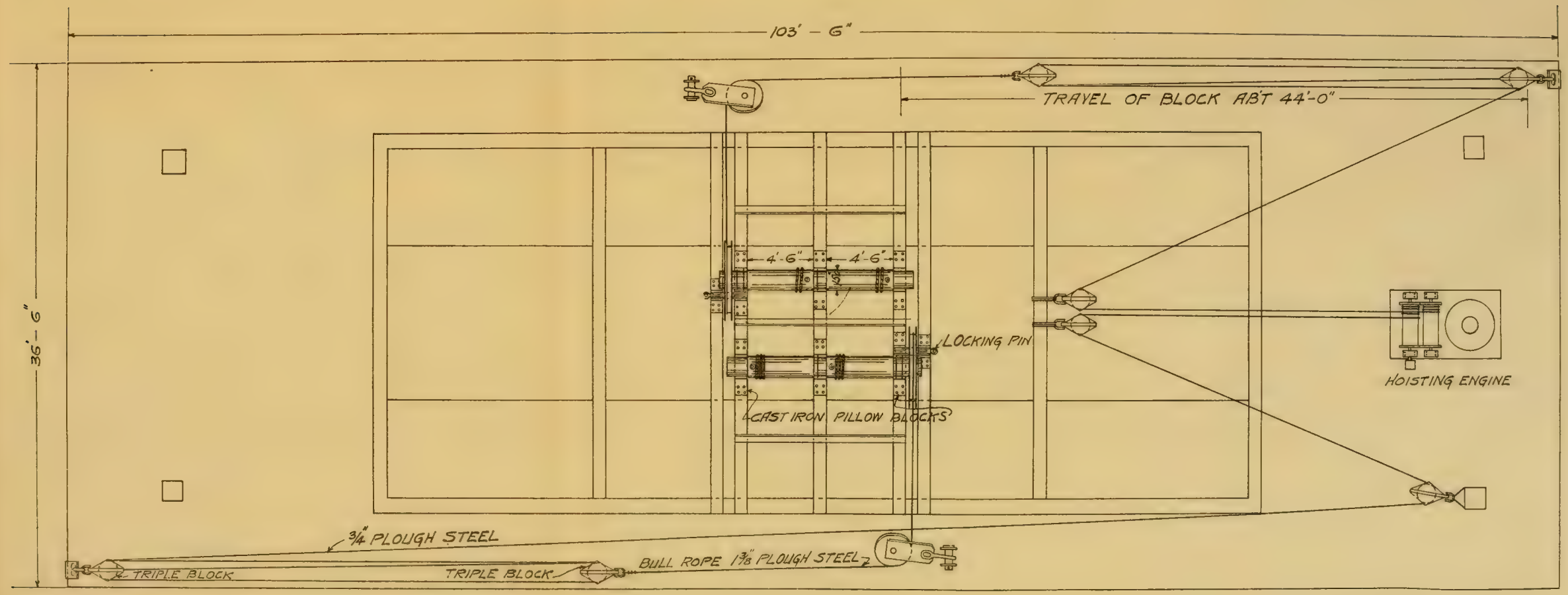
Fig. 12.—Bow Pontoons Emerging.

To illustrate paper on "Salvage Equipment Used in Raising Submarine F-4," by Naval Constructor J. A. Furer, U. S. N., Member.

Fig. 13.—All Pontoons on the Surface. Making Preparations to Tow Submarine into the Harbor.

Fig. 14.—Towing the F-4 into Port, Suspended from the Pontoons.

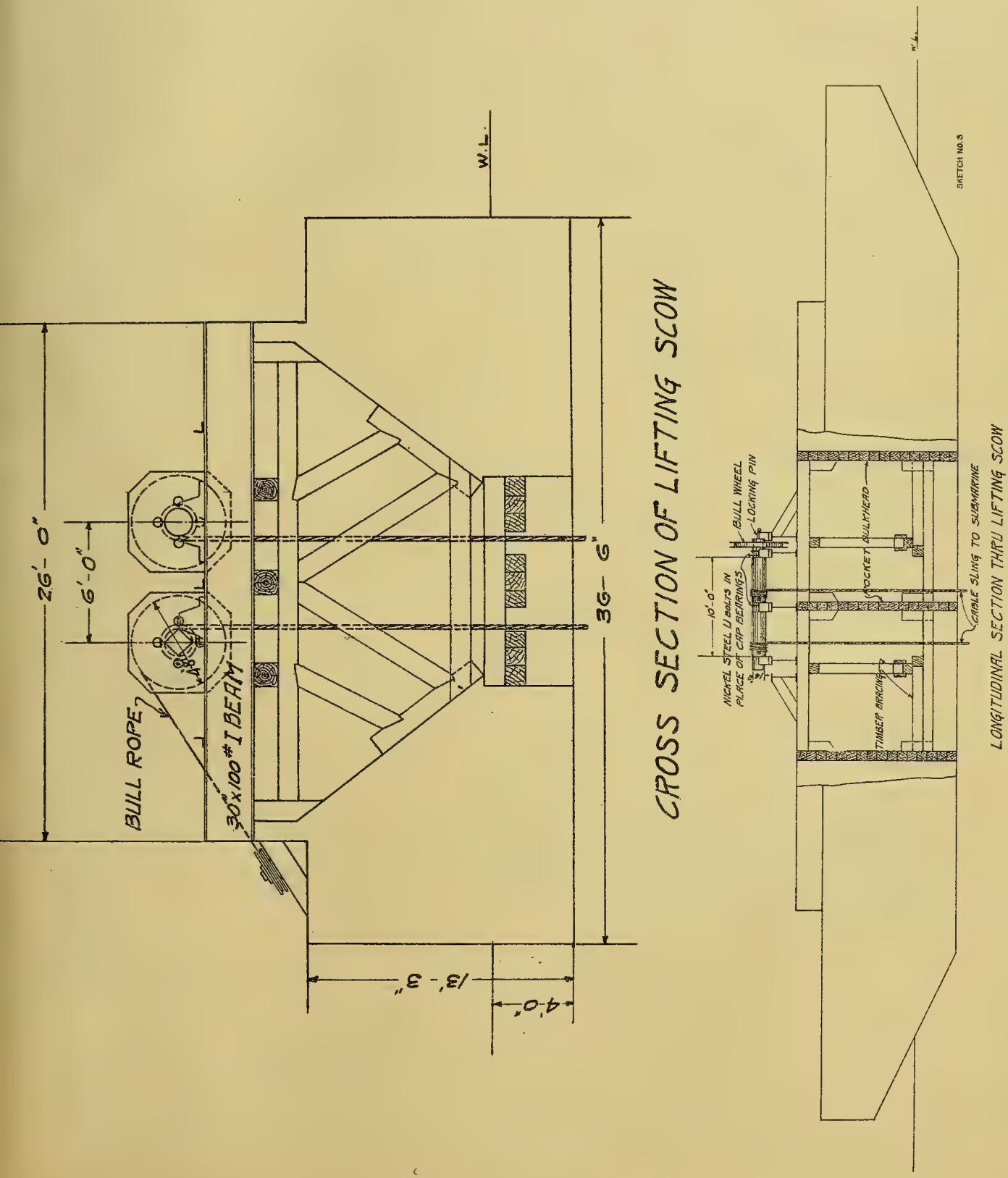
To illustrate paper on "Salvage Equipment Used in Raising Submarine F-4," by Naval Constructor J. A. Furer, U. S. N., Member.



PLAN VIEW OF LIFTING SCOW

SKETCH NO. 1.

To illustrate paper on "Salvage Equipment Used in Raising Submarine F-4," by Naval Constructor J. A. Furer, U. S. N., Member.



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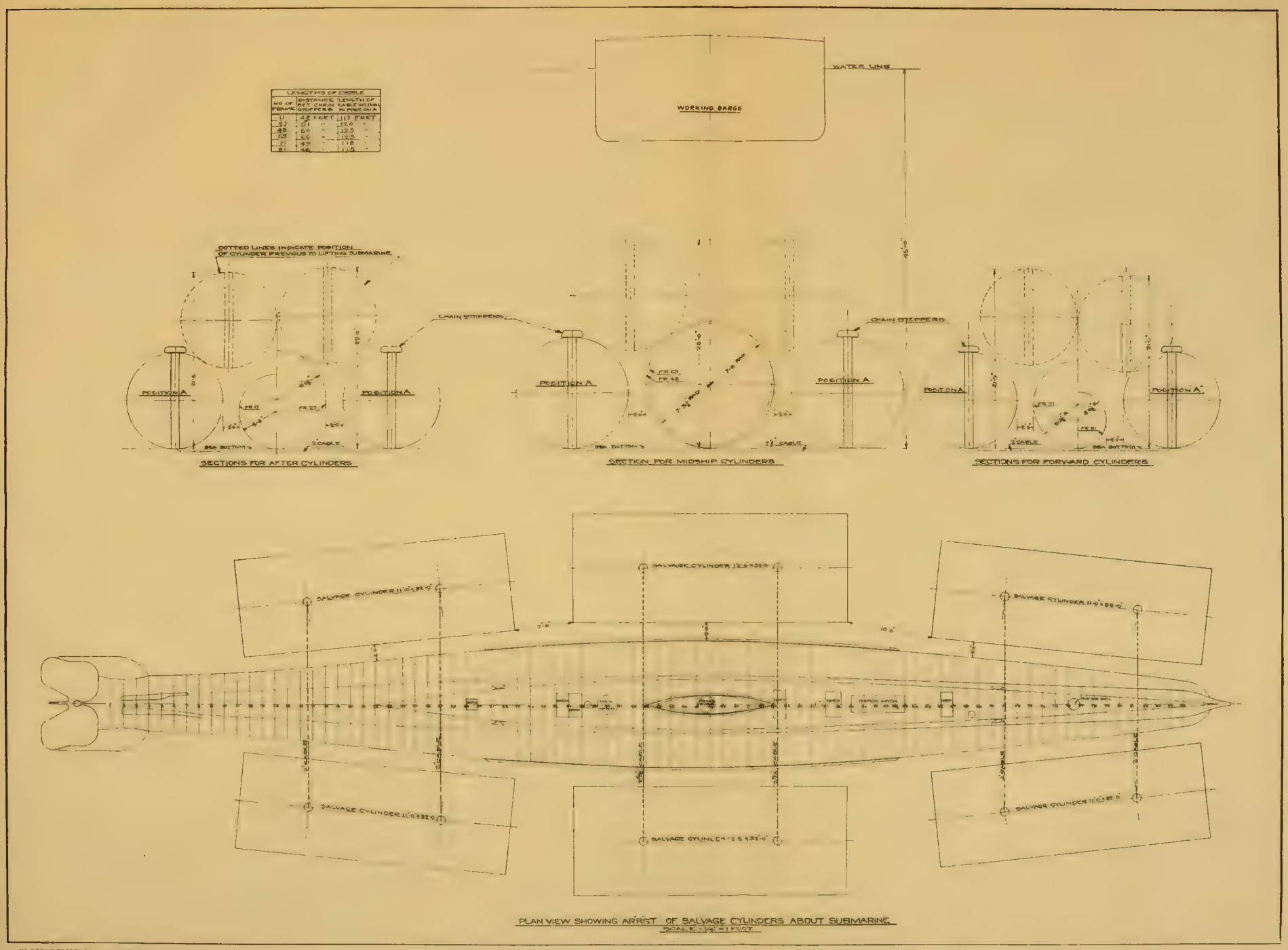

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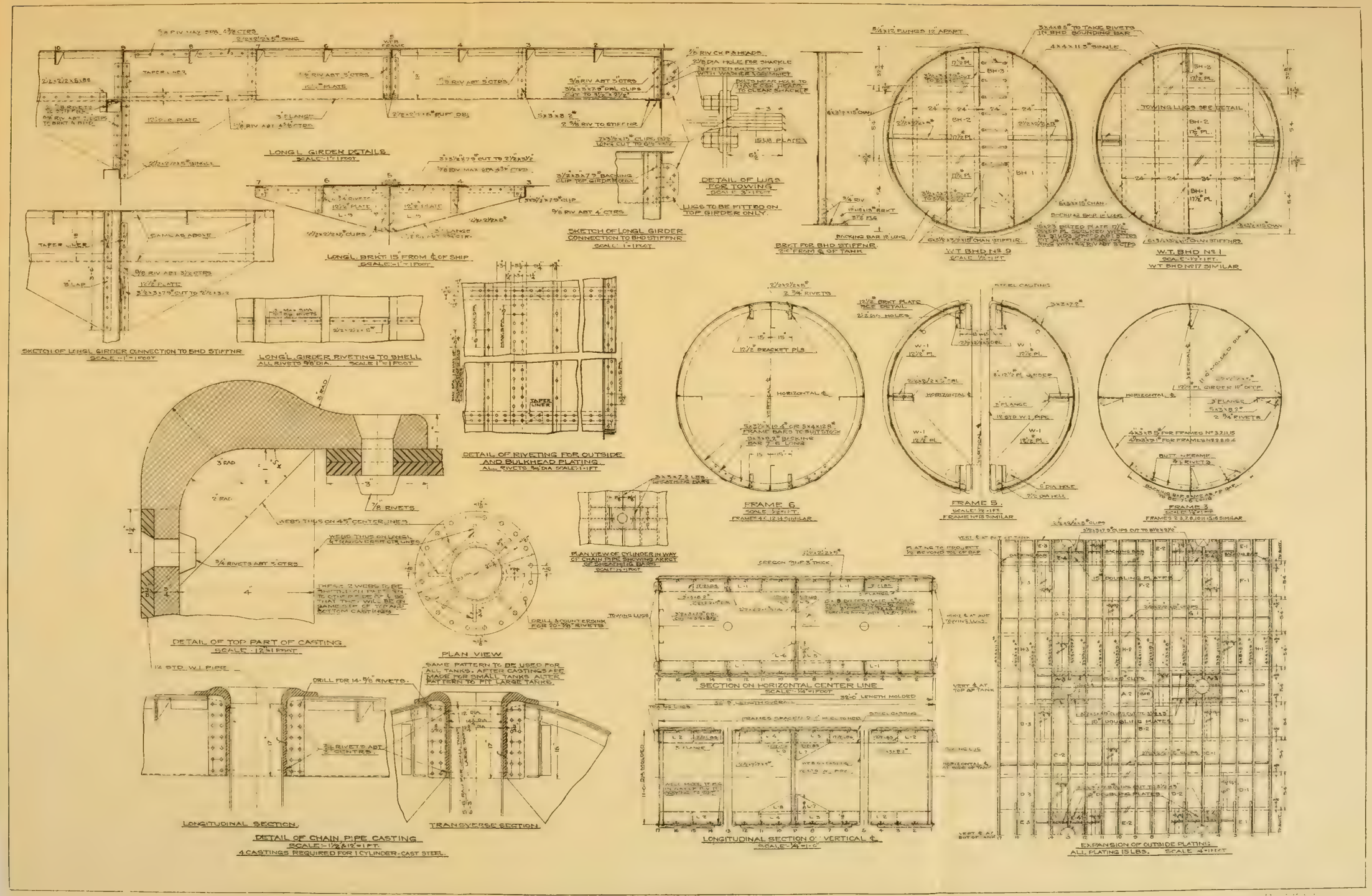
To illustrate paper on "Salvage Equipment Used in Raising Submarine F-4," by Naval Constructor J. A. Furer, U. S. N., Member.



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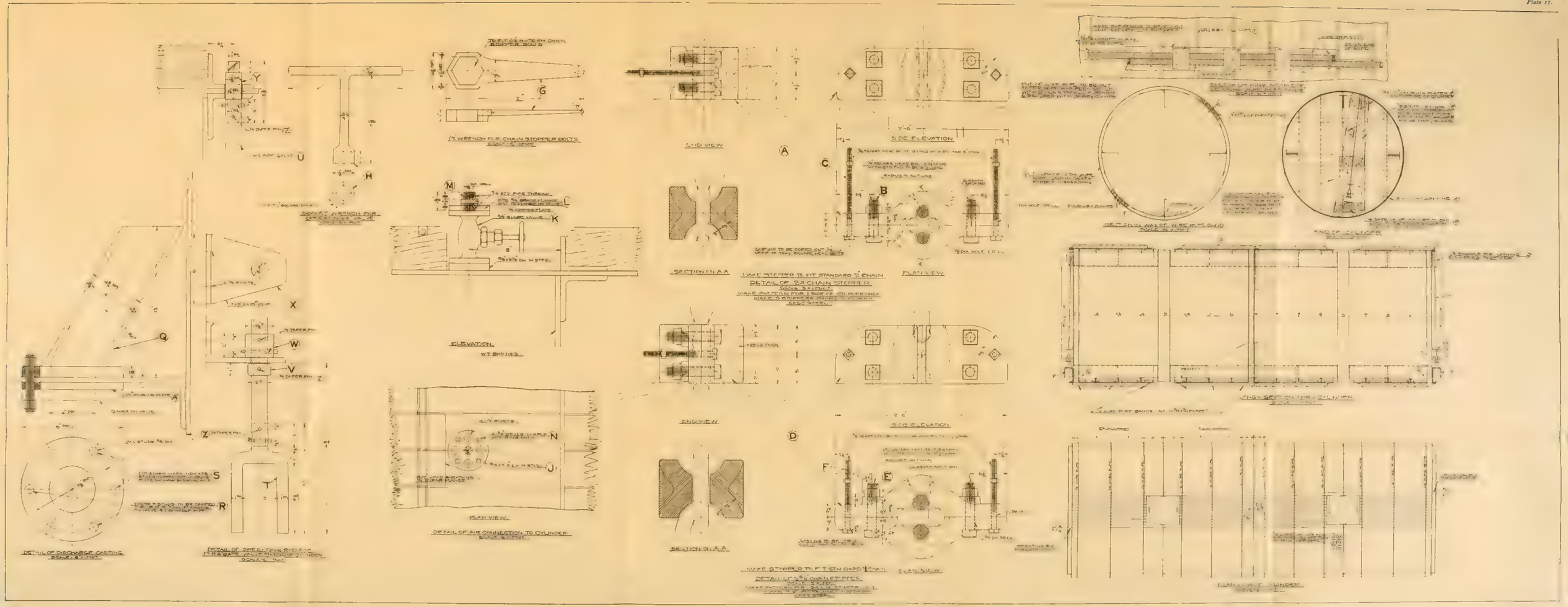
by Naval Constructor J. A. Furer, U. S. N., Member



To illustrate paper on "The Design of an Oil Engine," by John F. Wentworth, Esq., Member.

SHEET A.

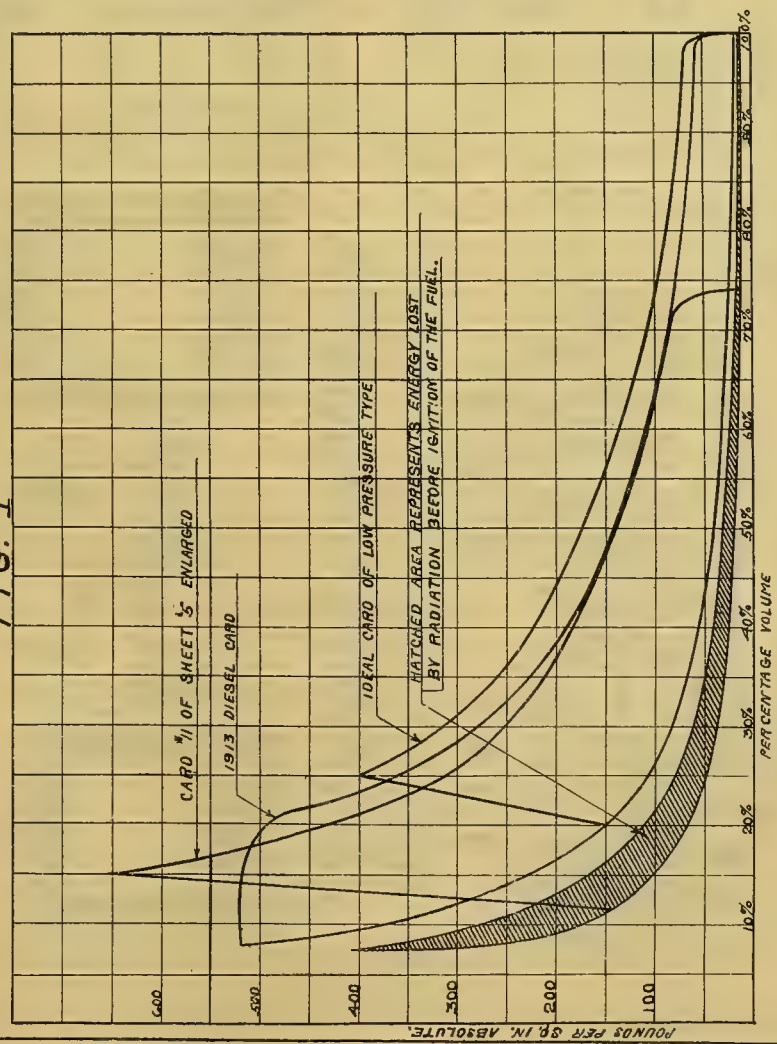
FIG. 2

DESCRIPTION	DATA	
ENGINE SIZES	12"X12"	60"X60"
PISTON AREA	113.1□"	2827.4□"
" CIRCUMFERENCE	37.7"	188.5"
" DISPLACEMENT	1357 cu. in.	172500 cu. in.
CYLINDER CONTENTS DIESEL	1460 " "	185500 " "
" " LOW PRES.	1697 " "	215500 " "
LENGTH OF CYLINDER DIESEL	12.91"	64.60"
" " " LOW PRES.	15"	75"
CLEARANCE VOLUME DIESEL	103 cu. in.	13000 cu. in.
" " LOW PRES.	340 " "	43000 " "
" SURFACE DIESEL	260.□"	6622.□"
" " LOW PRES.	339.□"	8582.□"
⊗WT. OF AIR PER STROKE DIESEL	.0508 LBS	64.7 LBS
⊗" " " " LOW PRES.	0.592 "	7.53 "
RATIO CLEARANCE SURFACE (D:L.P.)	.788	.772
" " VOL. (DIESEL: L.PRES.)	.303	.303

⊗ TEMPERATURE OF AIR AT BEGINNING OF COMPRESSION IS 200°F.

COMPRESSION PRES. DIESEL 500 LBS.
" L.P. TYPE 135 "

FIG. 1



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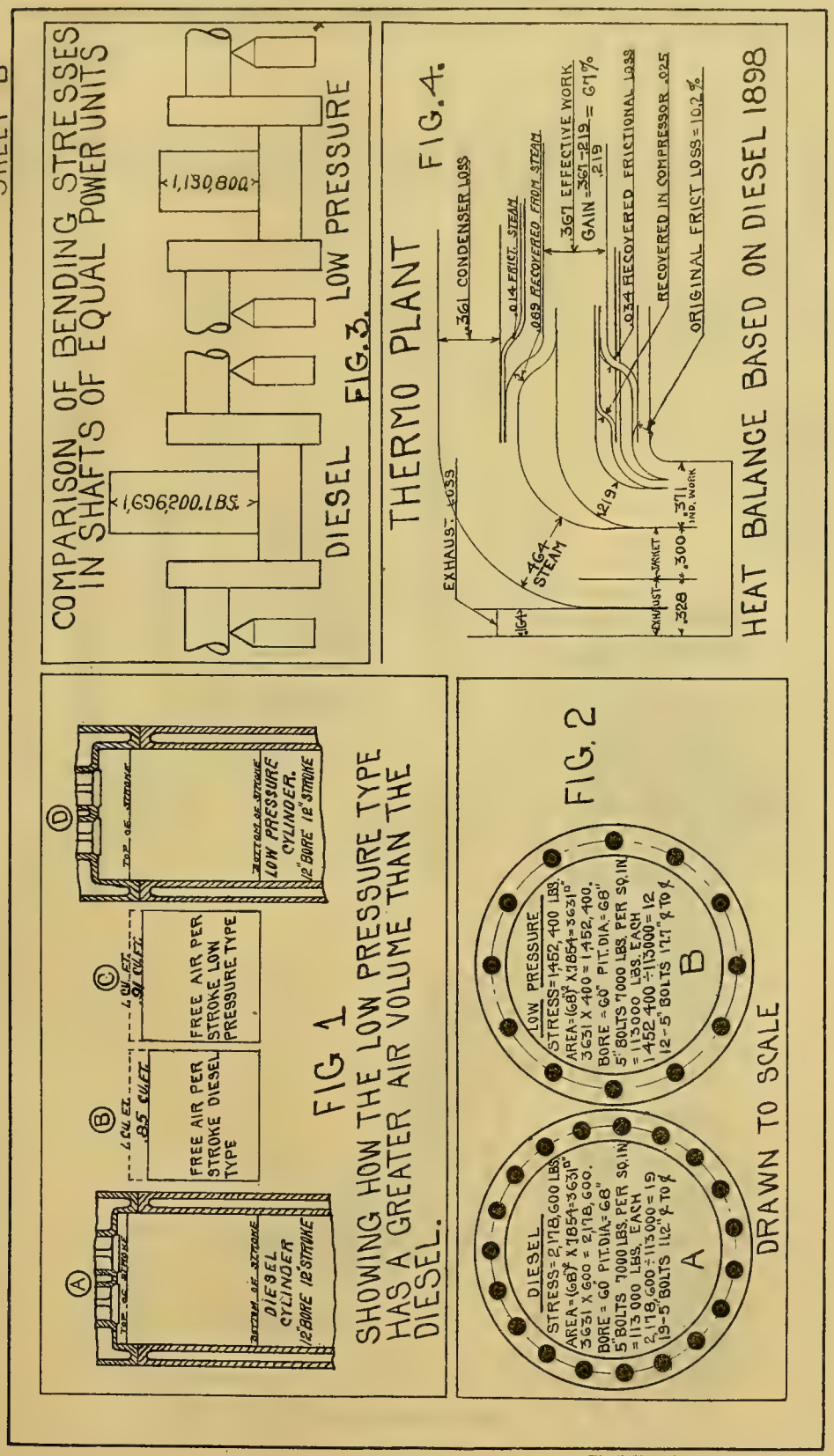
SHEET B



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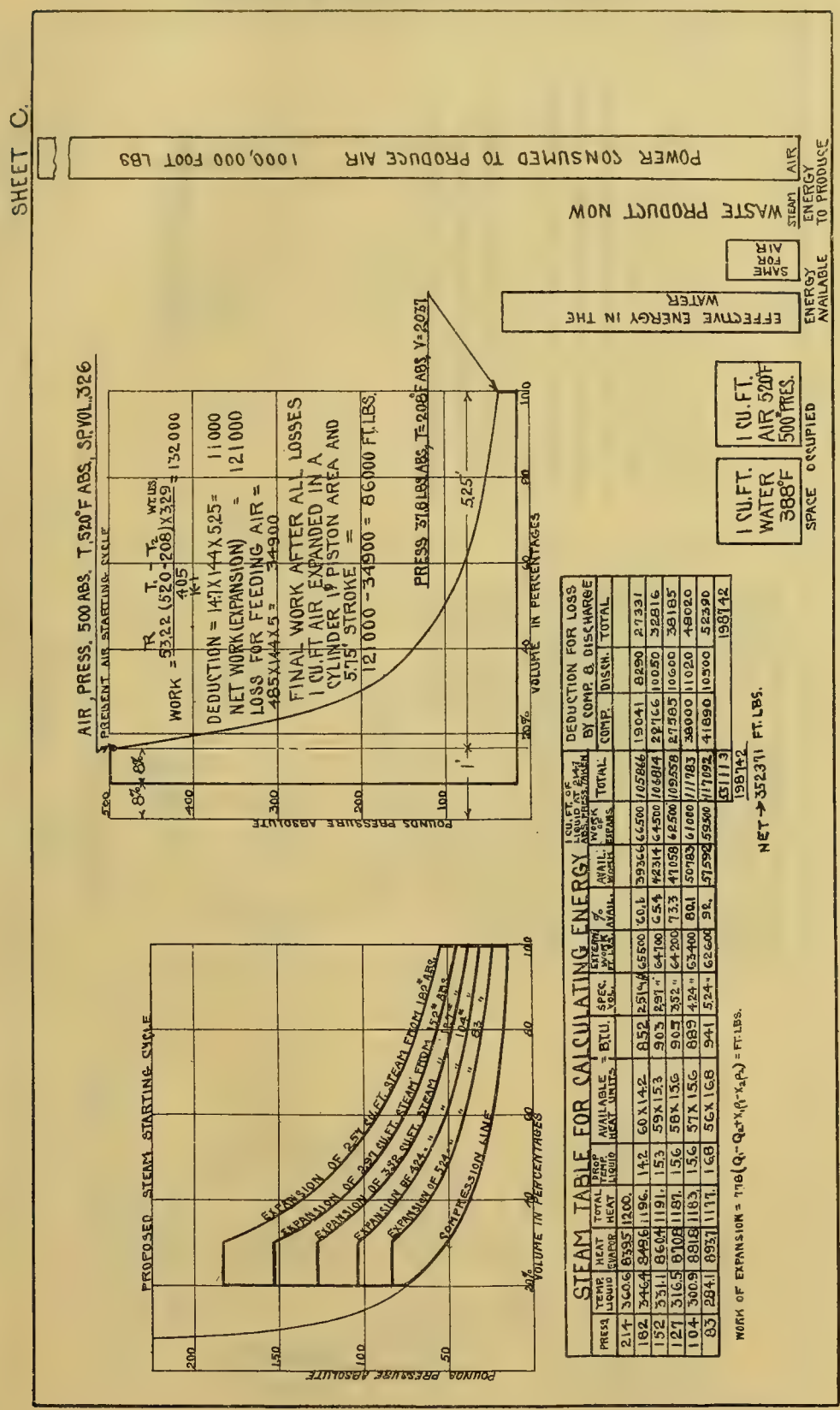

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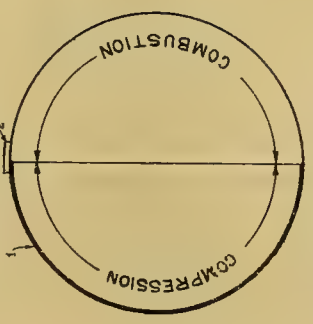
To illustrate paper on "The Design of an Oil Engine," by John F. Wentworth, Esq., Member.

FUEL FEEDING.

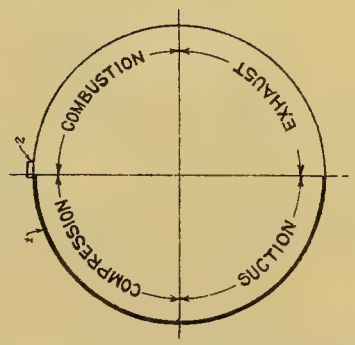
SHEET-D

ALL DIESEL TYPES.

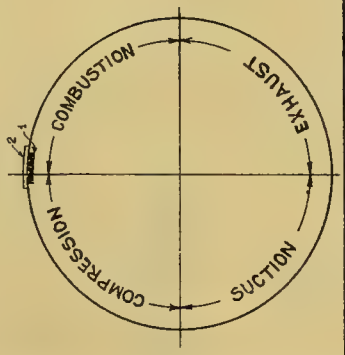
TWO CYCLE.



FOUR CYCLE.



WENTWORTH TYPE.



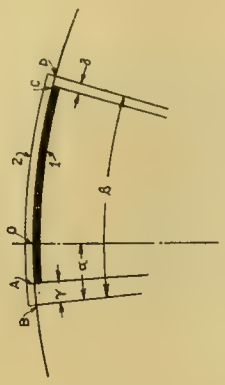
EXPLANATION OF FIGS 1, 2 & 3.

THE HEAVY BLACK LINE 1 REPRESENTS THE DURATION OF THE DELIVERY STROKE OF THE FUEL PUMP.

THE LIGHT SPACE (2) REPRESENTS THE DURATION OF THE FUEL VALVE OPENING.

FROM THIS IT WILL BE SEEN THAT THE DIESEL TYPES ACCUMULATE THE REQUIRED FUEL SUPPLY IN THE FUEL VALVE AS PER BRAYTON AND THEN TRUST TO LUCK FOR GETTING AN EVEN DELIVERY OF THE FUEL.

THE WENTWORTH TYPE DOES AWAY WITH THIS UNCERTAINTY BY FIRST STARTING THE INJECTION AIR AND THEN DELIVERING THE FUEL INTO THE MOVING STREAM OF AIR.



DETAIL OF WENTWORTH FUEL DELIVERY.

1-FUEL DELIVERY DURATION (A-C.)

2-DURATION OF FUEL VALVE OPENING (B-C.)

O-DEAD CENTER.

γ & δ SHOULD BE PRACTICALLY CONSTANT.

α THE ANGLE OF ADVANCE FOR OPENING OF THE FUEL VALVE SHOULD BE VARIABLE EITHER PLUS OR MINUS.

β THE DURATION OF THE FUEL VALVE OPENING TO SUIT THE LOAD.

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SHEET – E

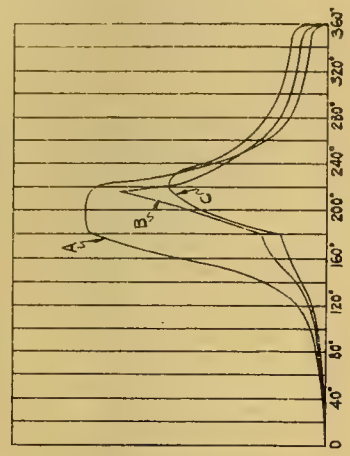

FIG. 2.

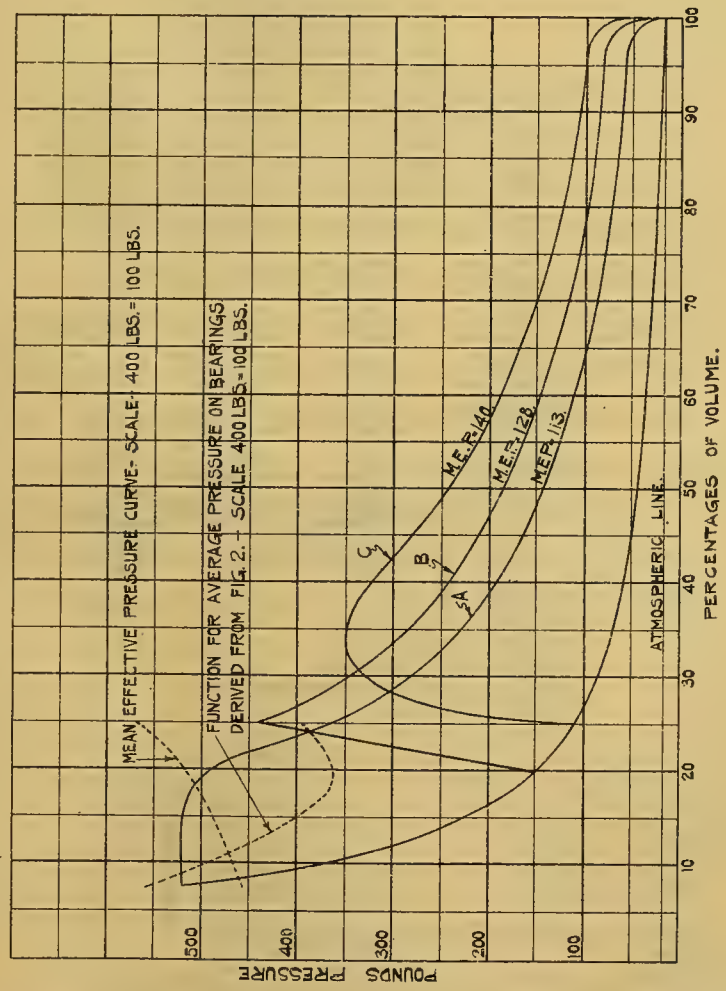

FIG. 1.

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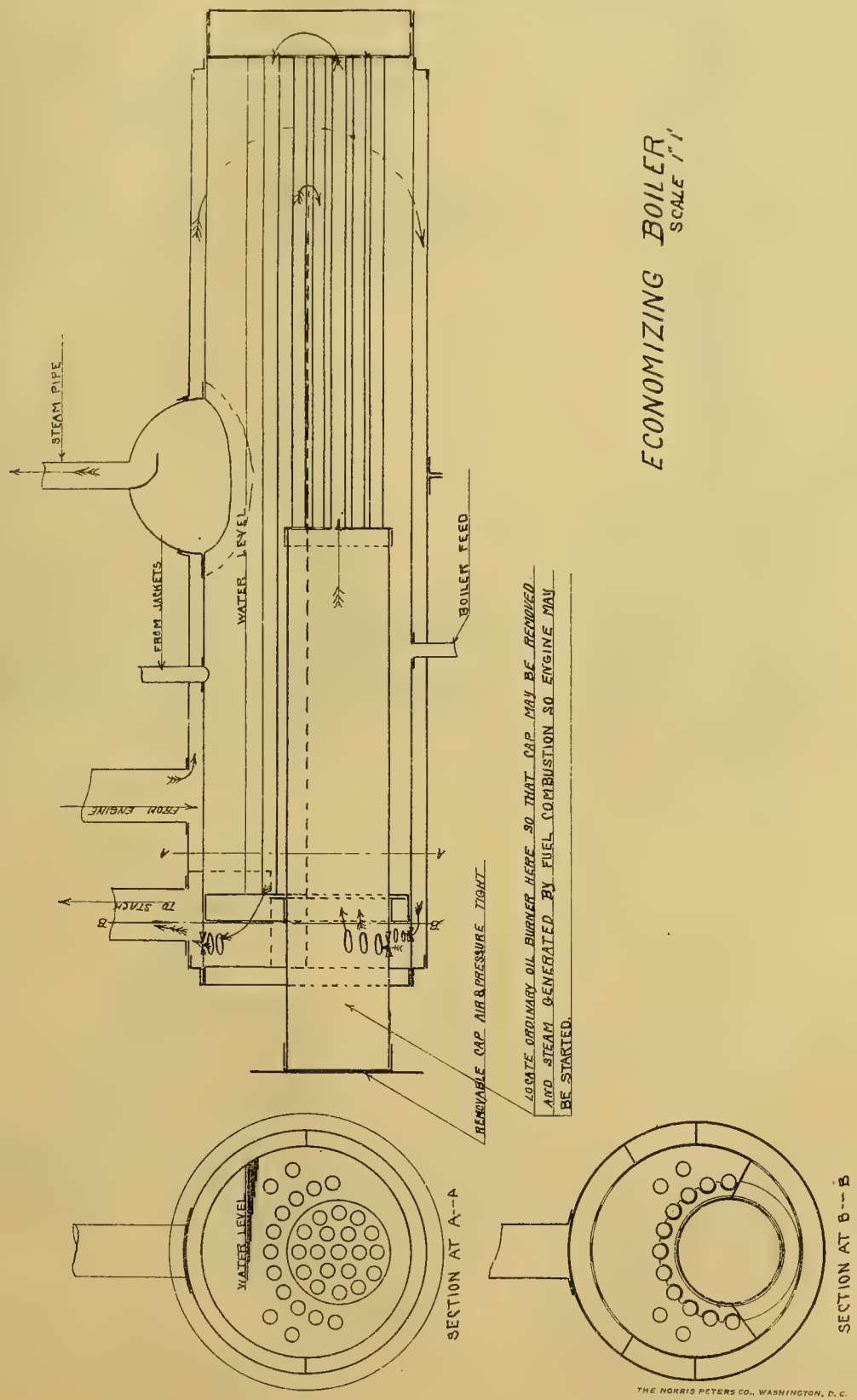

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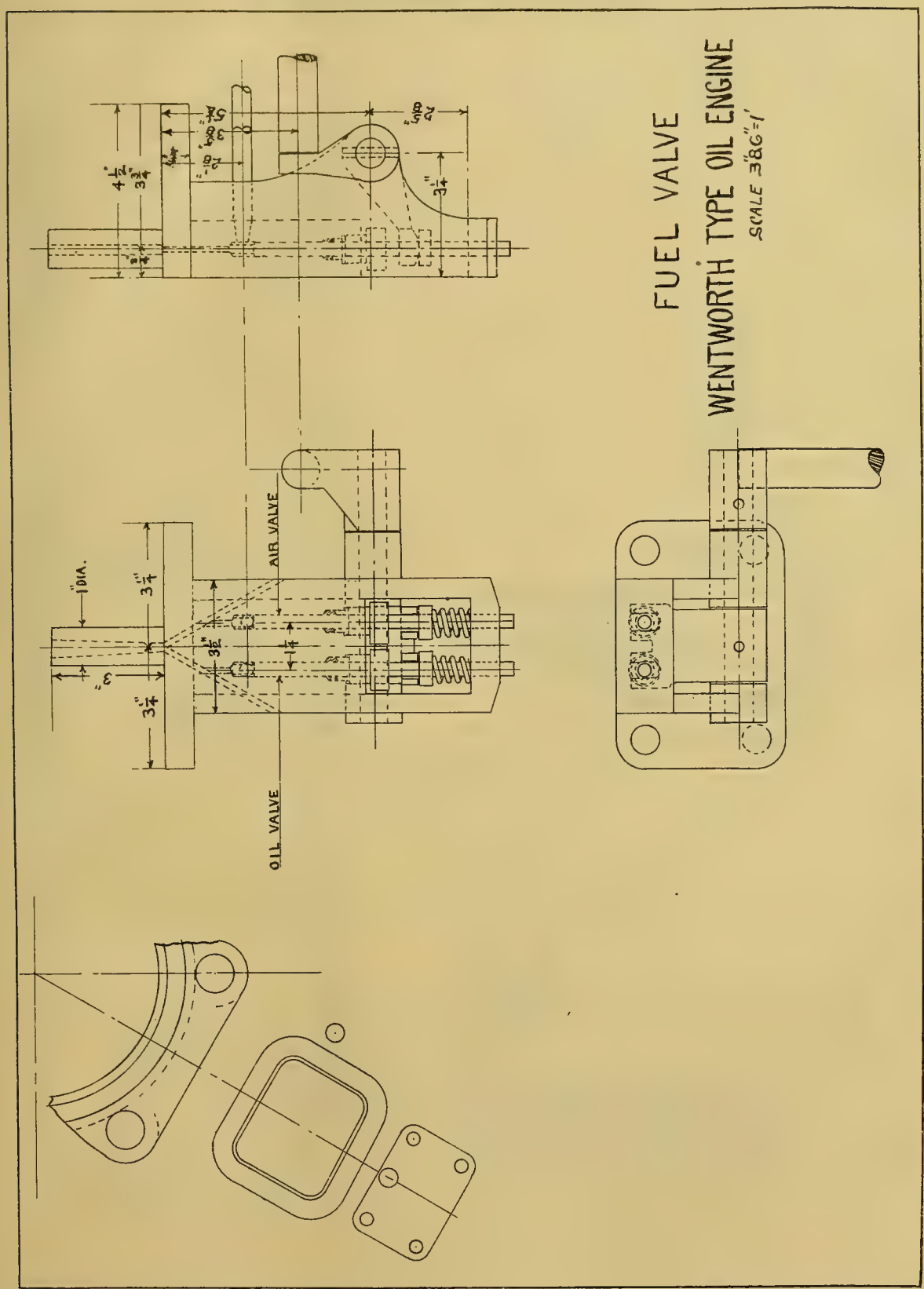

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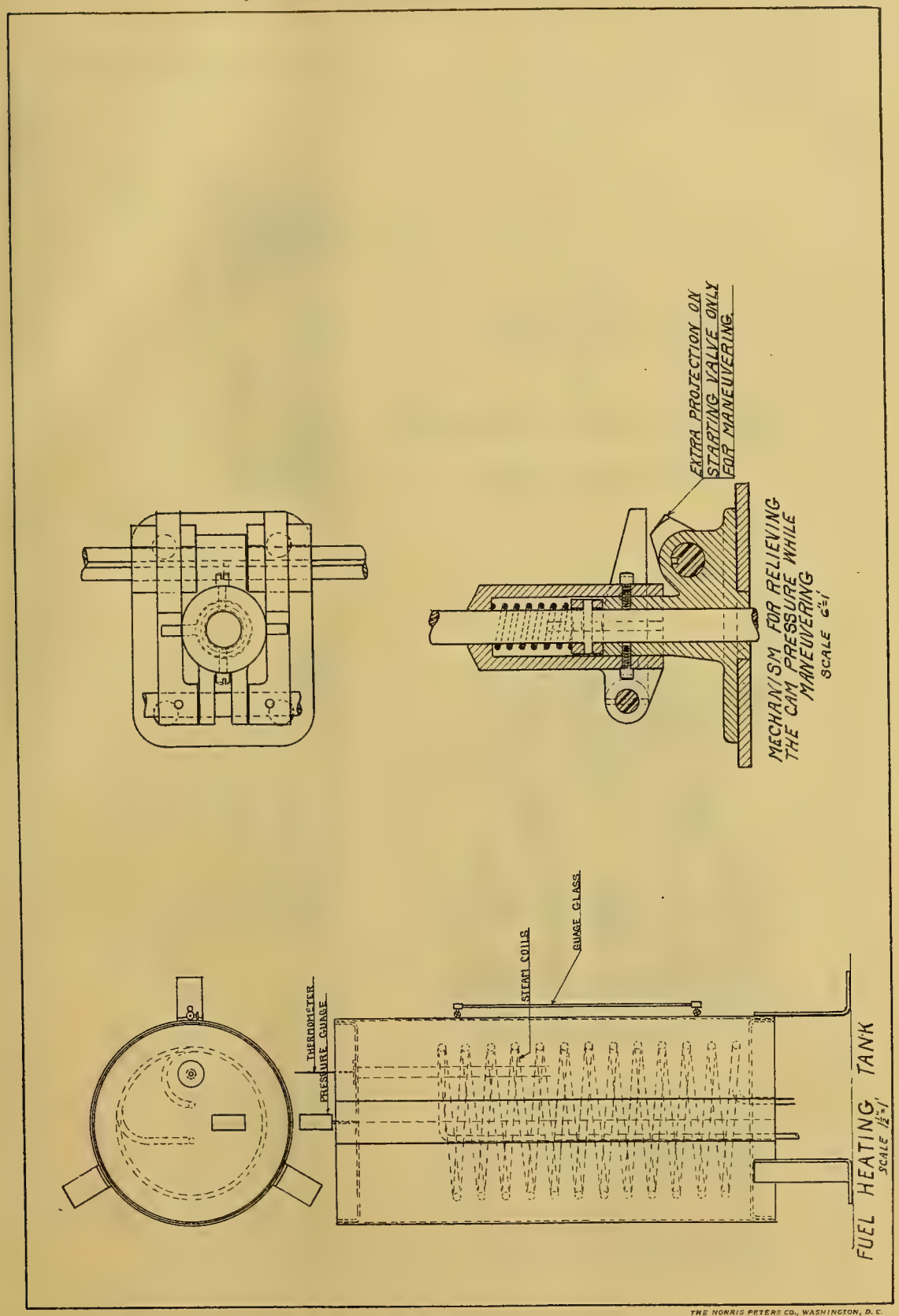

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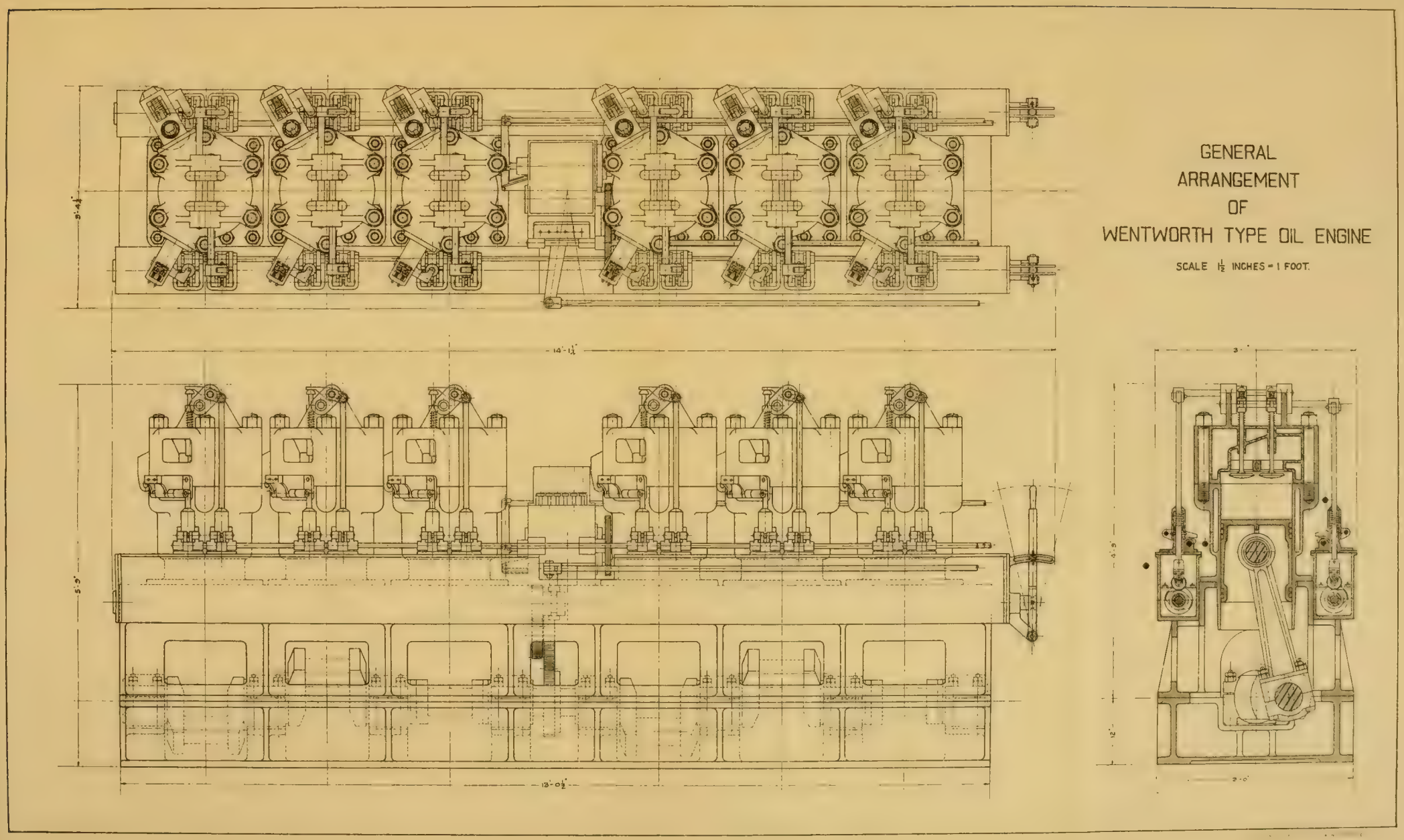

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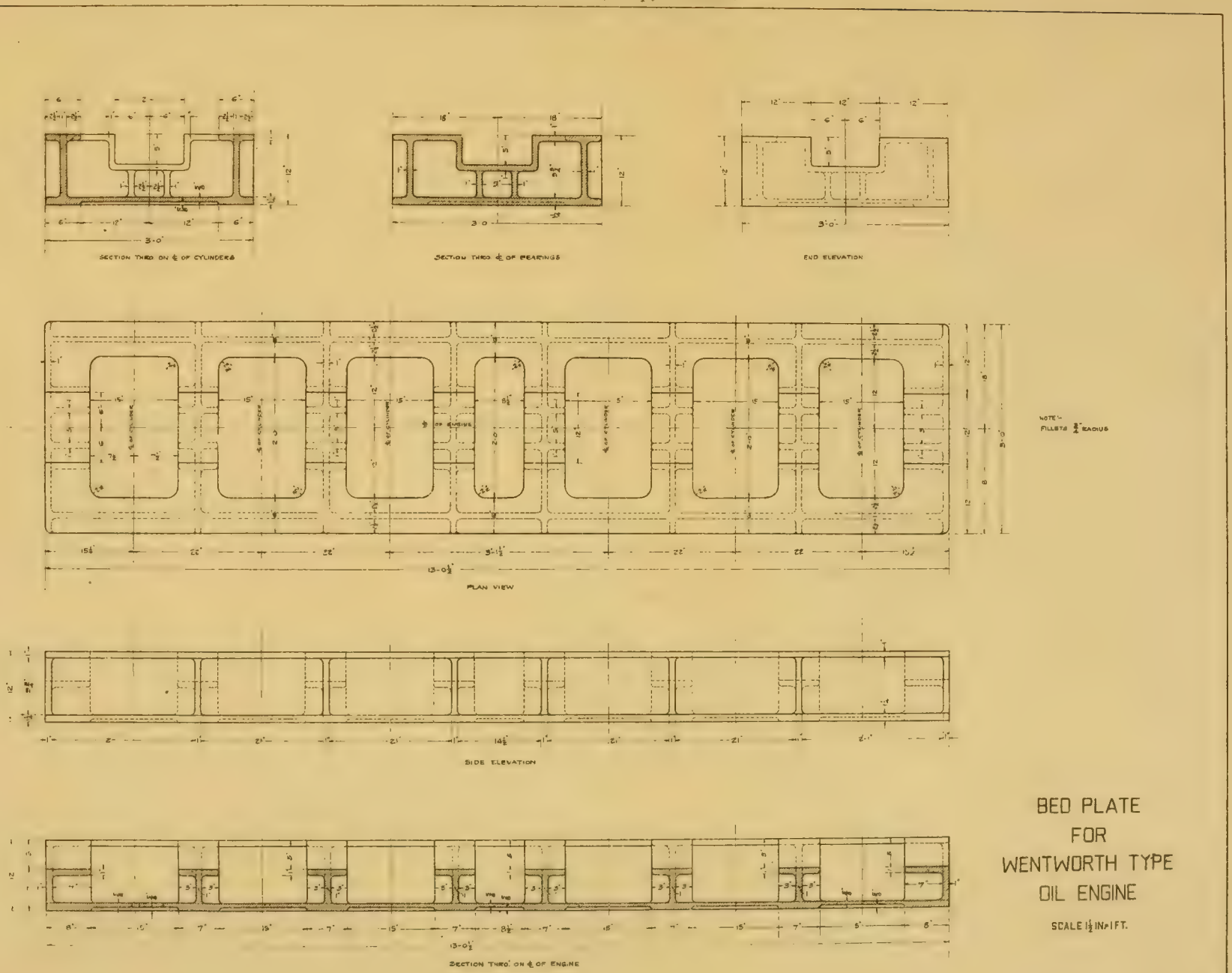

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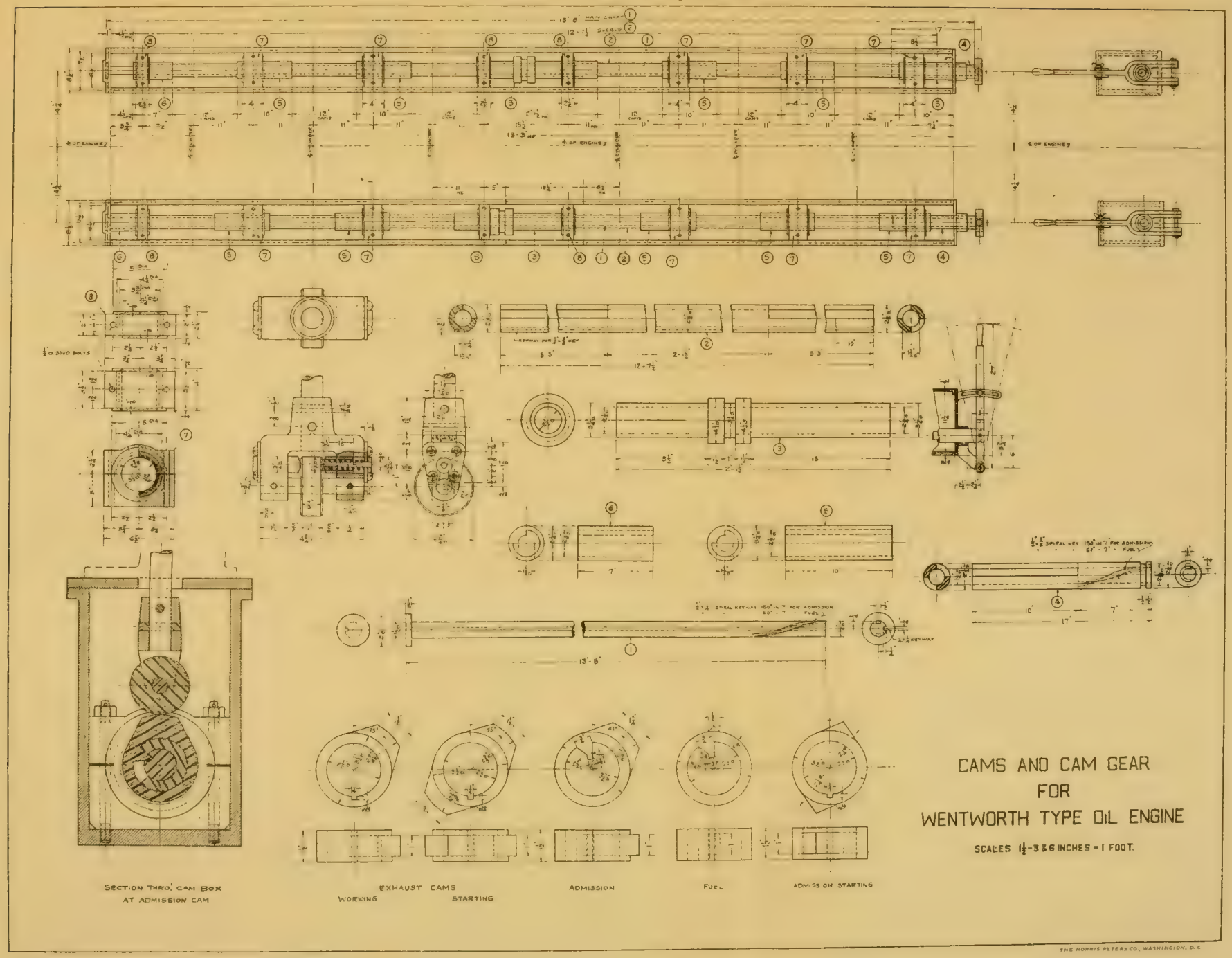

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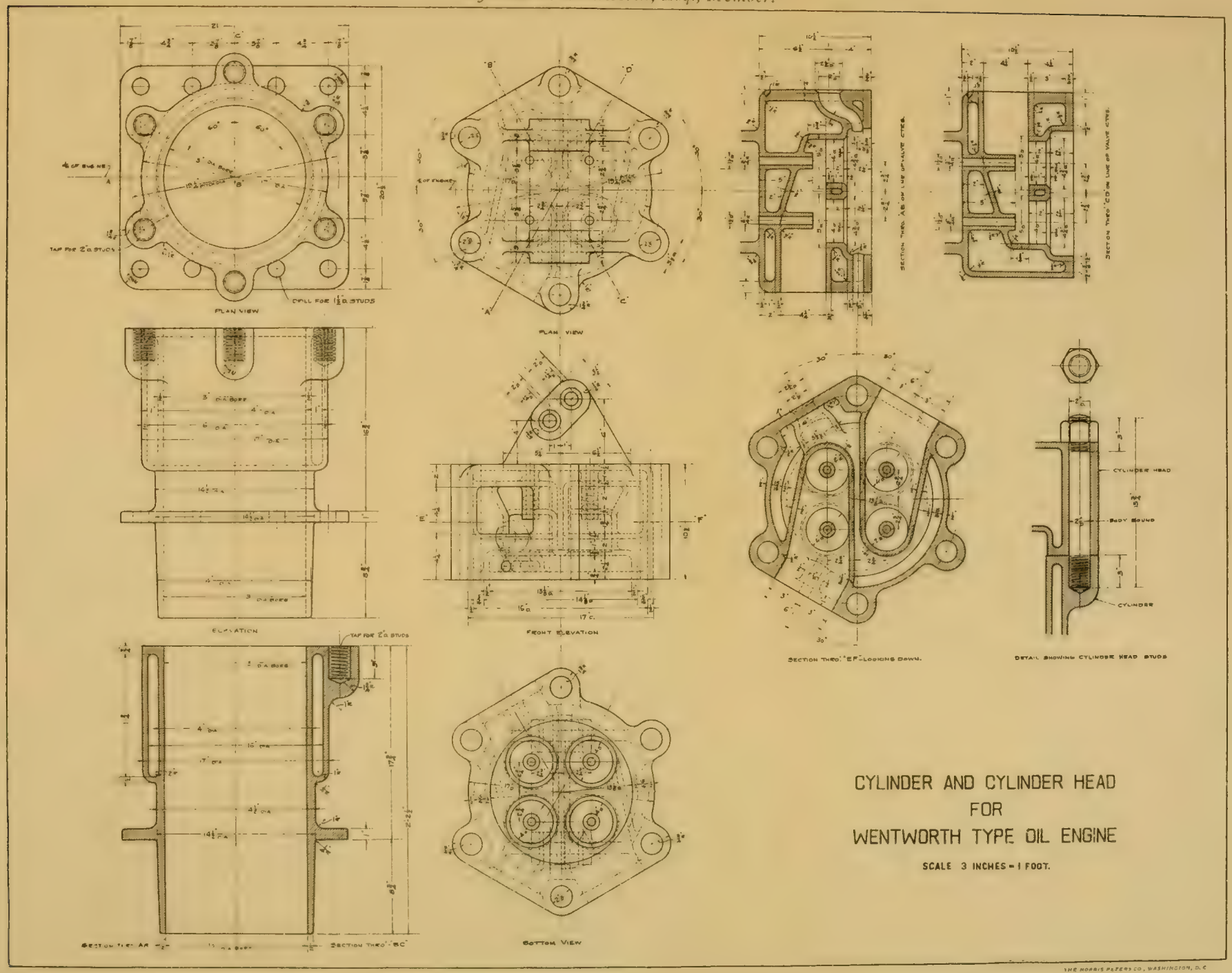

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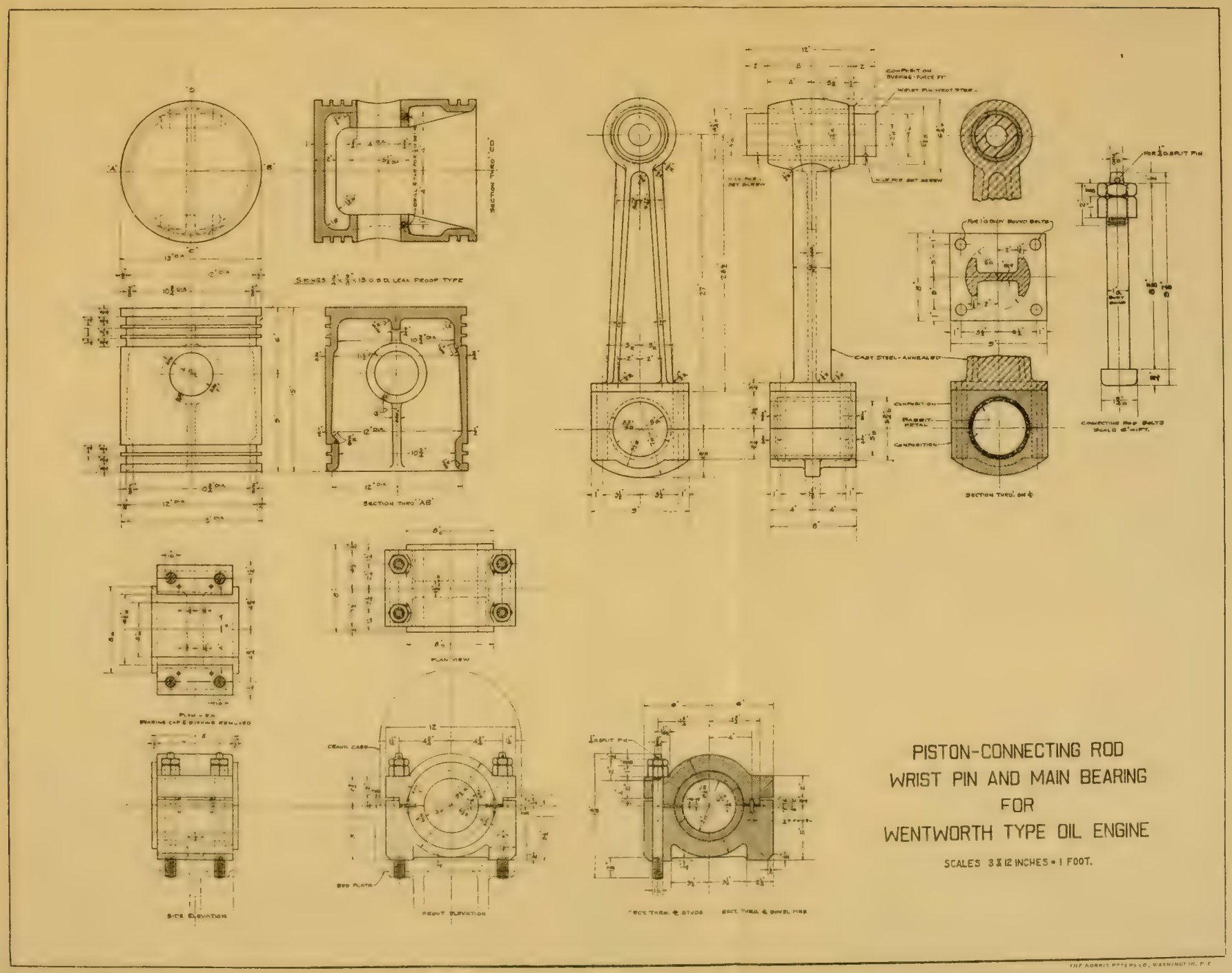

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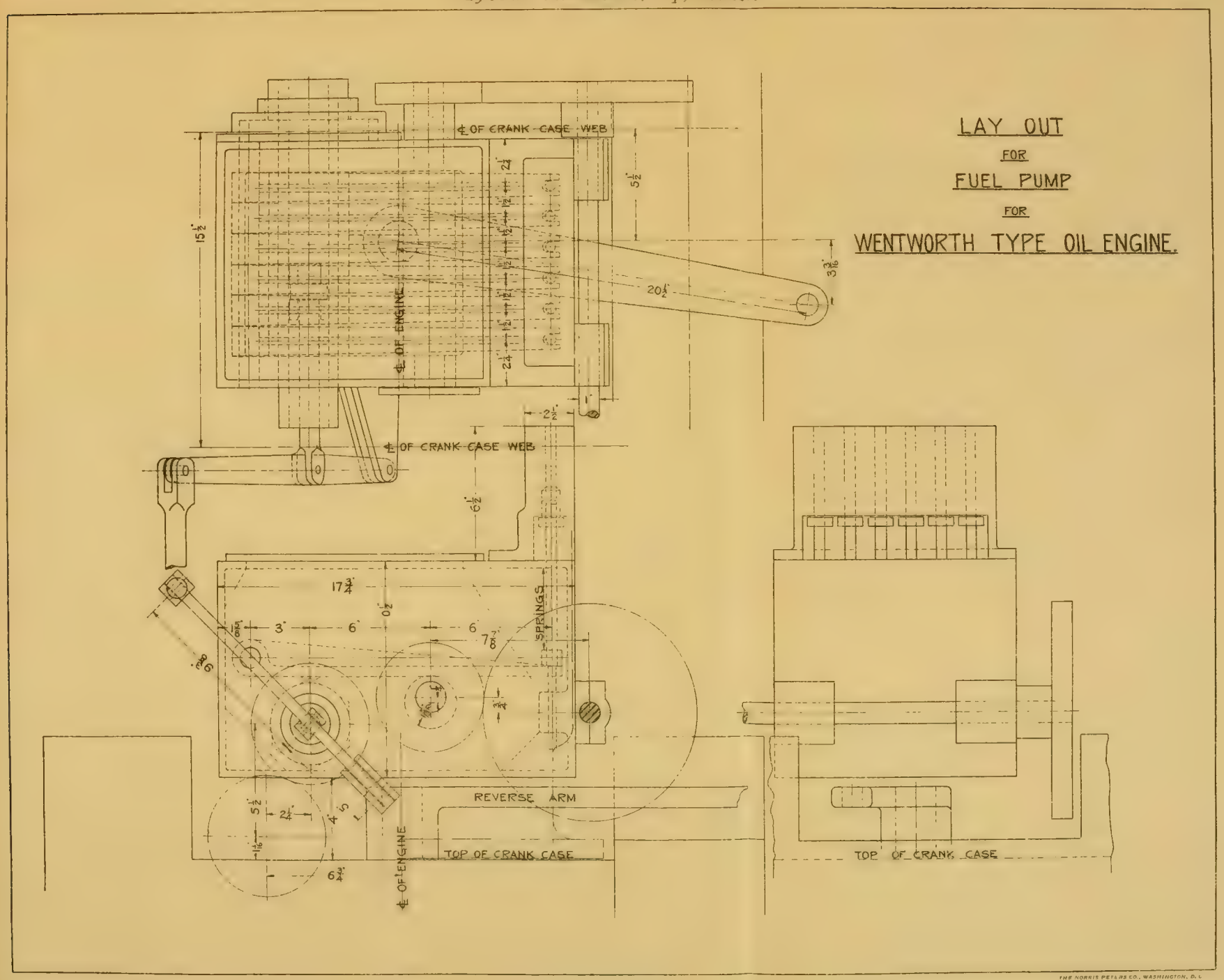

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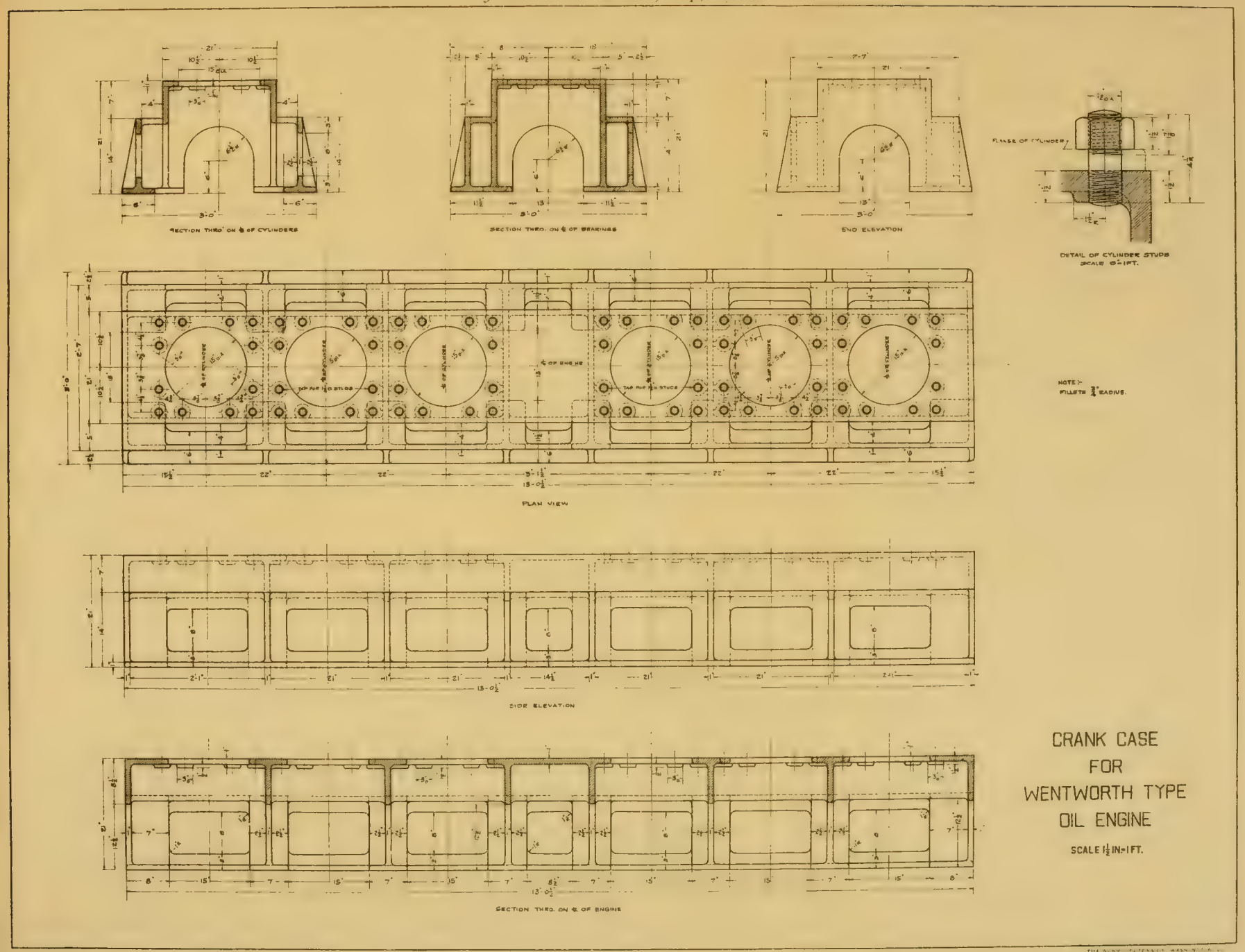
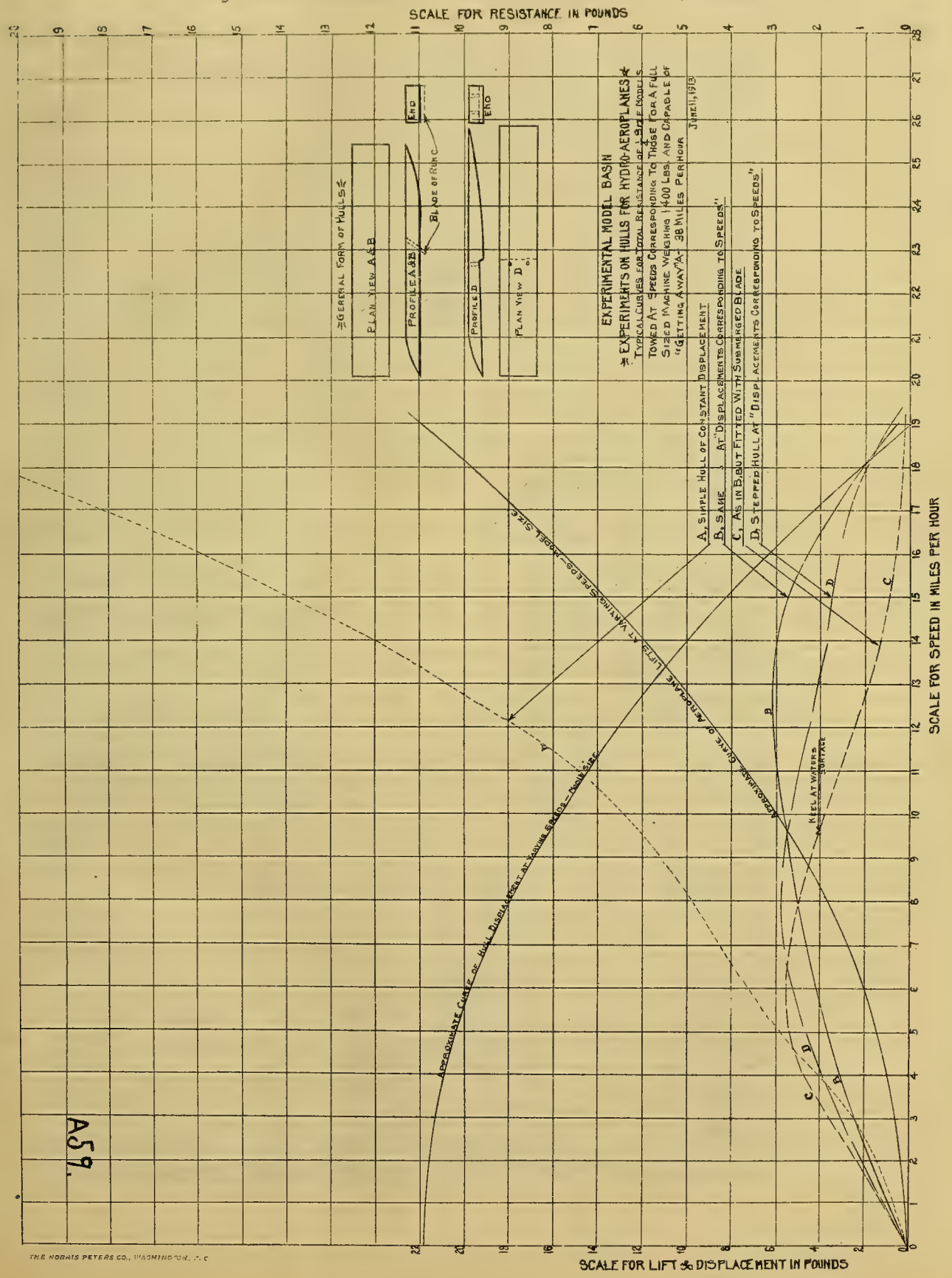
To illustrate paper on "The Design of an Oil Engine," by John F. Wentworth, Esq., Member.

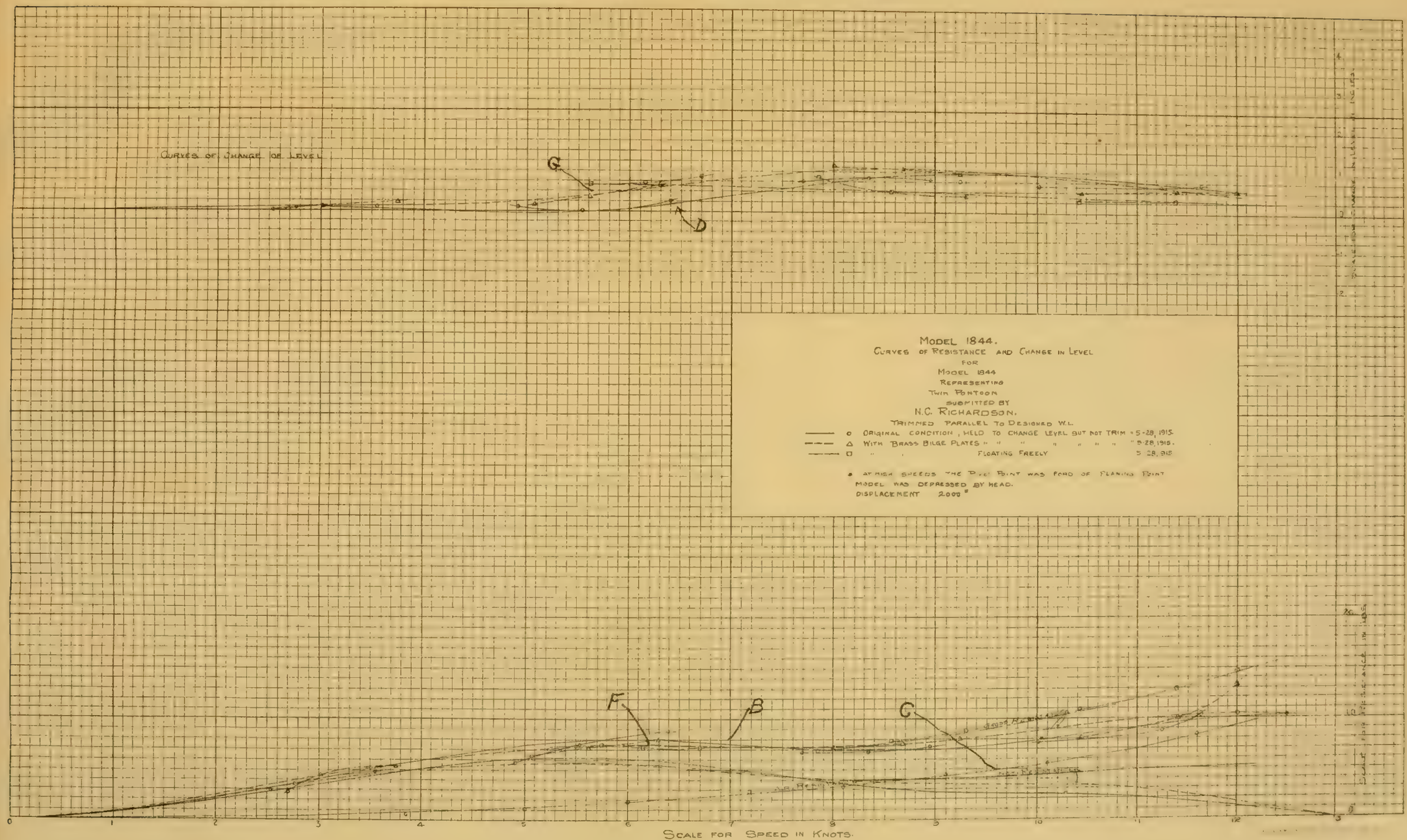


To illustrate paper on "Aeronautics in Relation to Naval Architecture," by Naval Constructor H. C. Richardson, U. S. N., Member.

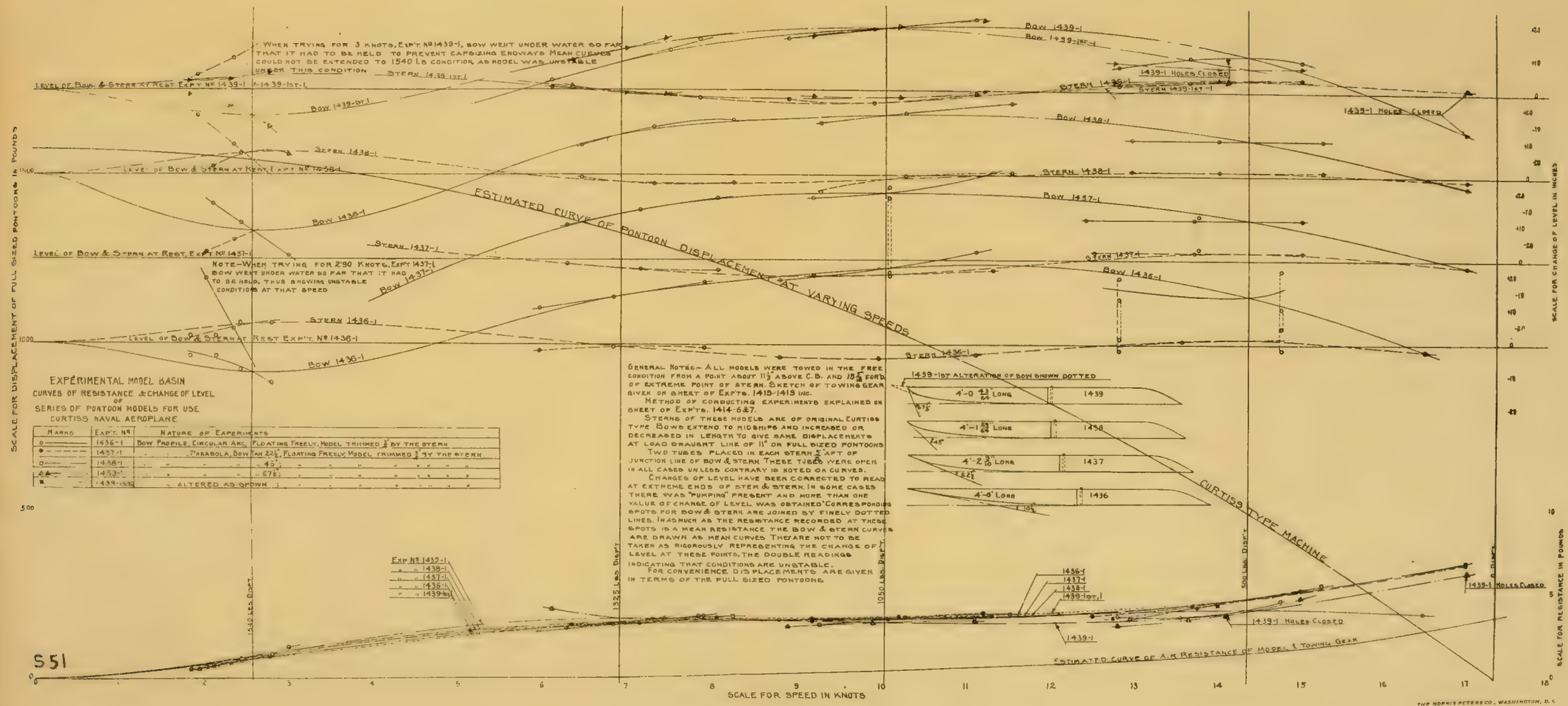


THE HORNIS PETERS CO., WASHINGTON, D. C.

To illustrate paper on "Aeronautics in Relation to Naval Architecture," by Naval Constructor H. C. Richardson, U. S. N., Member.



To illustrate paper on "Aeronautics in Relation to Naval Architecture," by Naval Constructor H. C. Richardson, U. S. N., Member.



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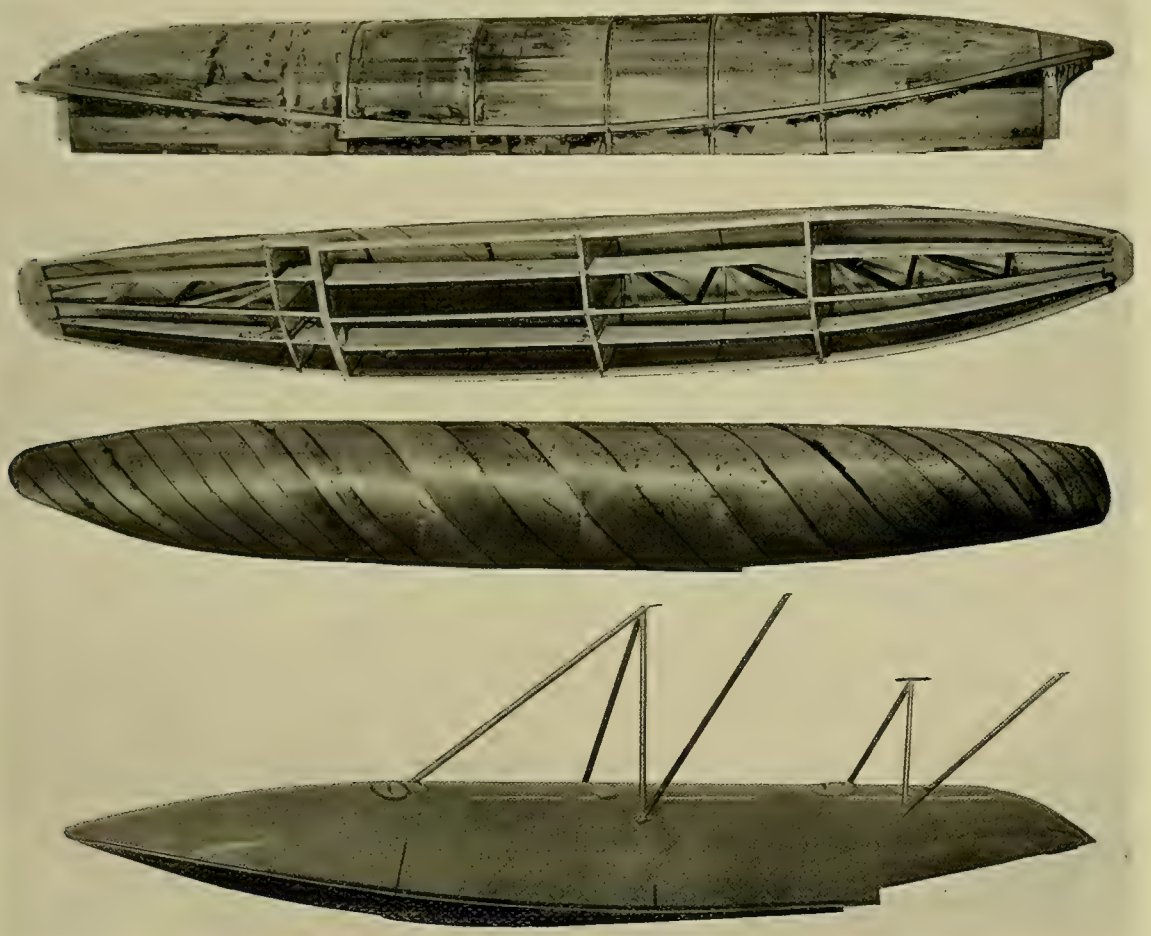
To illustrate paper on "Aeronautics in Relation to Naval Architecture," by Naval Constructor H. C. Richardson, U. S. N., Member.



FLOAT CONSTRUCTION AT DIFFERENT STAGES.

To illustrate paper on "The Power-Forging of Chain Cables," by Naval Constructor F. G. Coburn, U. S. N., Member.

Fig 1.—Hand-Welded Triplet No. 2, Open-Link Chain. Note Irregularities of Shape and Rough Appearance.

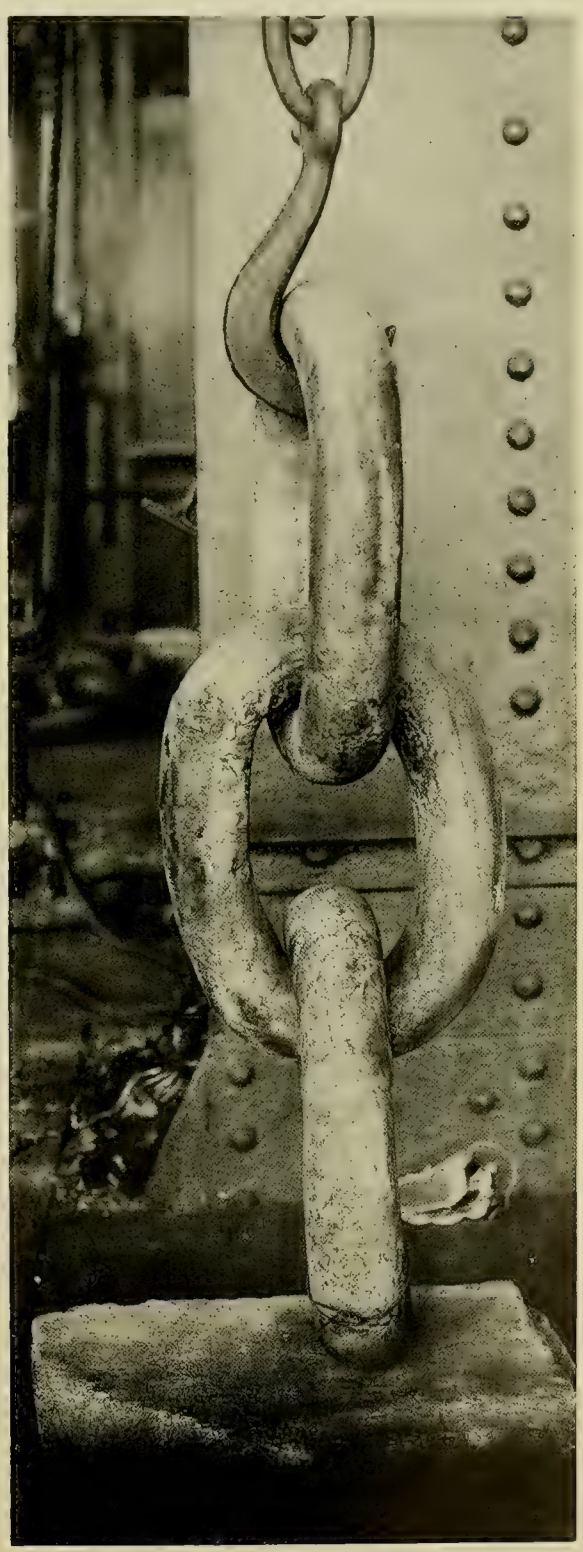


Fig. 2.—Hand-Welded Triplet No. 2, Open-Link Chain. Revolved 90° from Fig. 1, to Show Irregular Shape of Middle Link.

To illustrate paper on "The Power-Forging of Chain Cables," by Naval Constructor F. G. Coburn, U. S. N., Member.

Fig. 3.—Hand-Welded Triplet No. 2, Open-Link Chain, after Test to Destruction. Note Lifeless Appearance. Broke at 364,000 Pounds. 525,000 Pounds Required.

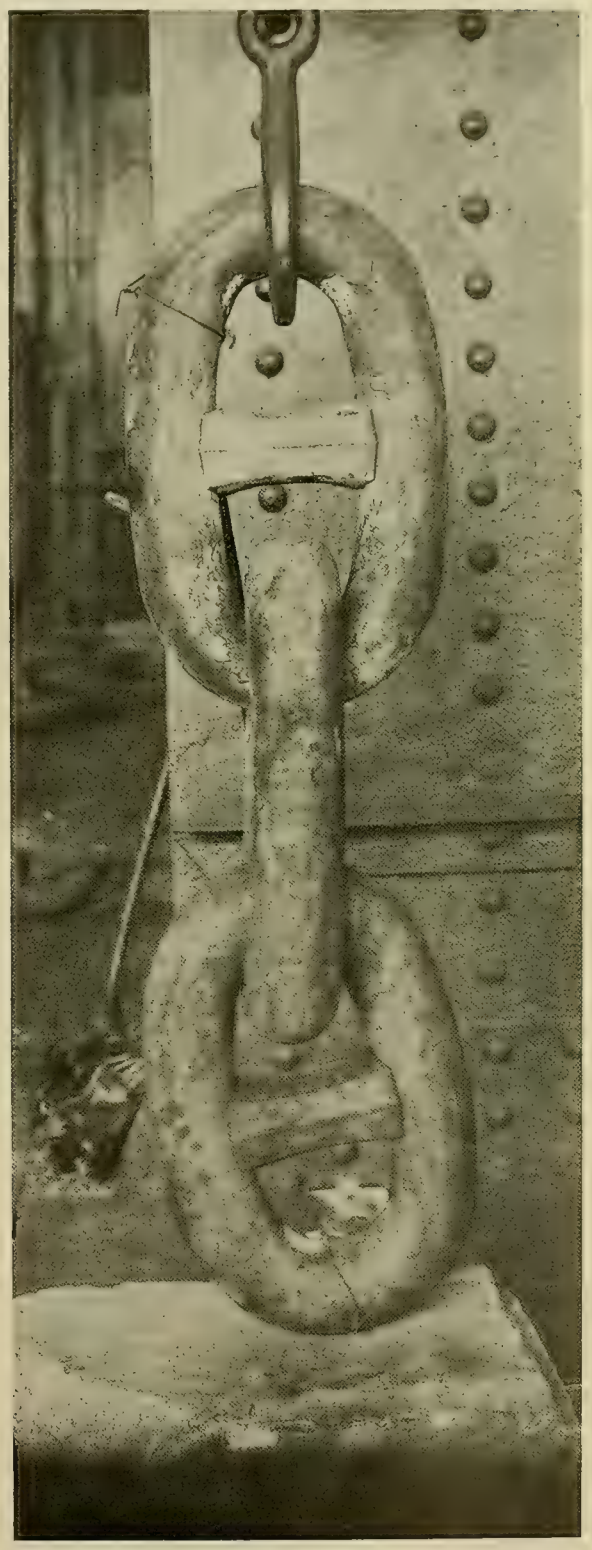


Fig. 4.—Hand-Welded Triplet No. 1, Stud-Link Chain. Rough and Irregular.

To illustrate paper on "The Power-Forging of Chain Cables," by Naval Constructor F. G. Coburn, U. S. N., Member.

Fig. 5.—Hand-Welded Triplet No. 1, Stud-Link Chain. Tested to Destruction. Broke at 390,000 Pounds. 525,000 Pounds Required.

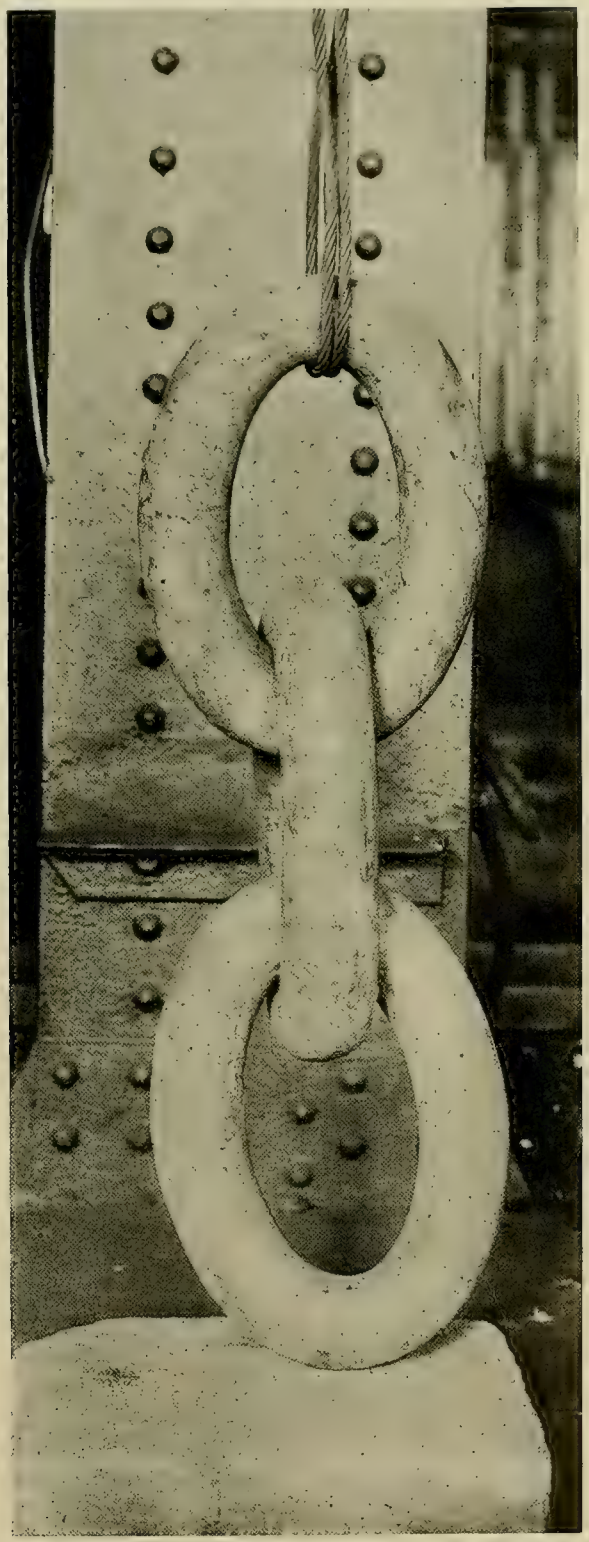


Fig. 6.—Power-Welded Triplet No. 3, Open-Link Chain. Smooth Forged, Regular in Shape.

To illustrate paper on "The Power-Forging of Chain Cables," by Naval Constructor F. G. Coburn, U. S. N., Member.

Fig. 7.—Power-Welded Triplet No. 3, Open-Link Chain. Tested to Destruction. Looks Tough and Well Put Together. Broke at 532,000 Pounds. 525,000 Pounds Required. It Exceeded the Requirement for Stud-Link Chain.

Fig. 8.—3¼″ Test Triplet. This Chain Weighs 595 Pounds Per Fathom, and Runs 6 Links Per Fathom. Ultimate Strength 612,000 Pounds. For Battleships of the Pennsylvania Class.

To illustrate paper on "The Power-Forging of Chain Cables," by Naval Constructor F. G. Coburn, U. S. N., Member.

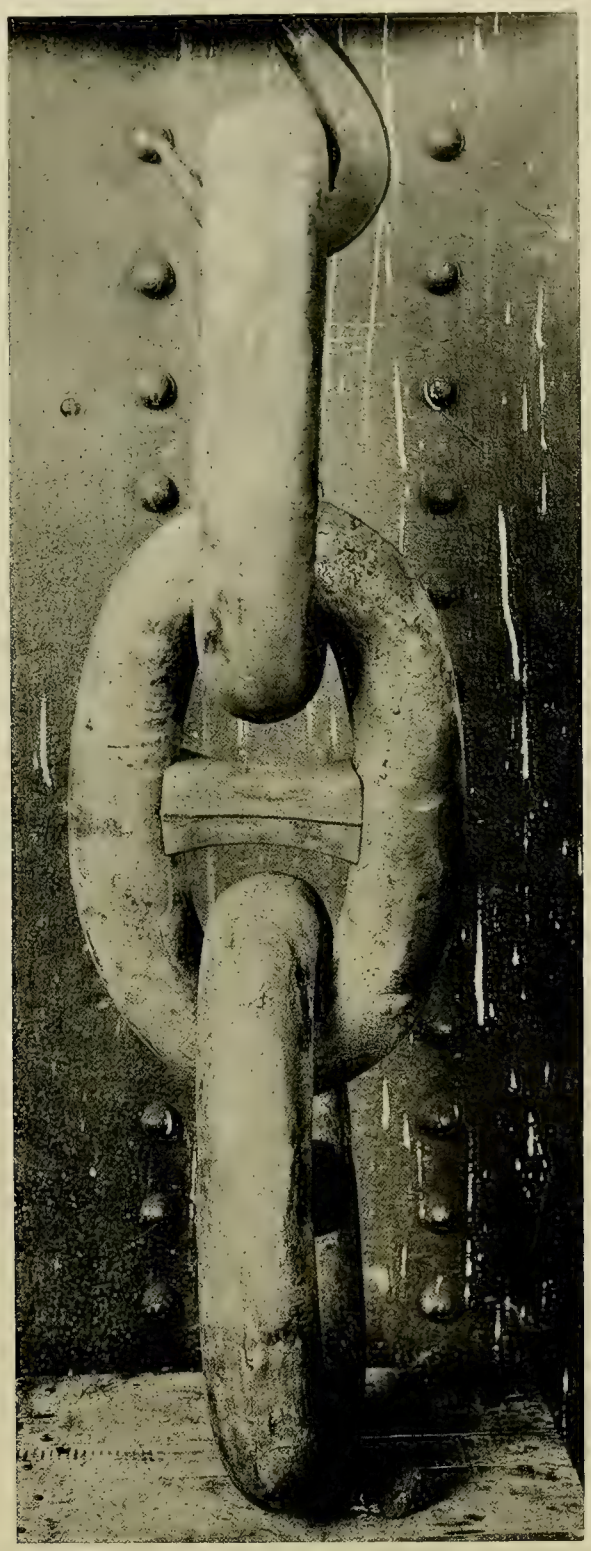


Fig. 9.—3¼" Test Triplet. This Chain Weighs 595 Pounds Per Fathom, and Runs 6 Links Per Fathom. Ultimate Strength 612,000 Pounds. For Battleships of the Pennsylvania Class.

To illustrate paper on "The Power-Forging of Chain Cables," by Naval Constructor F. G. Coburn, U. S. N., Member.

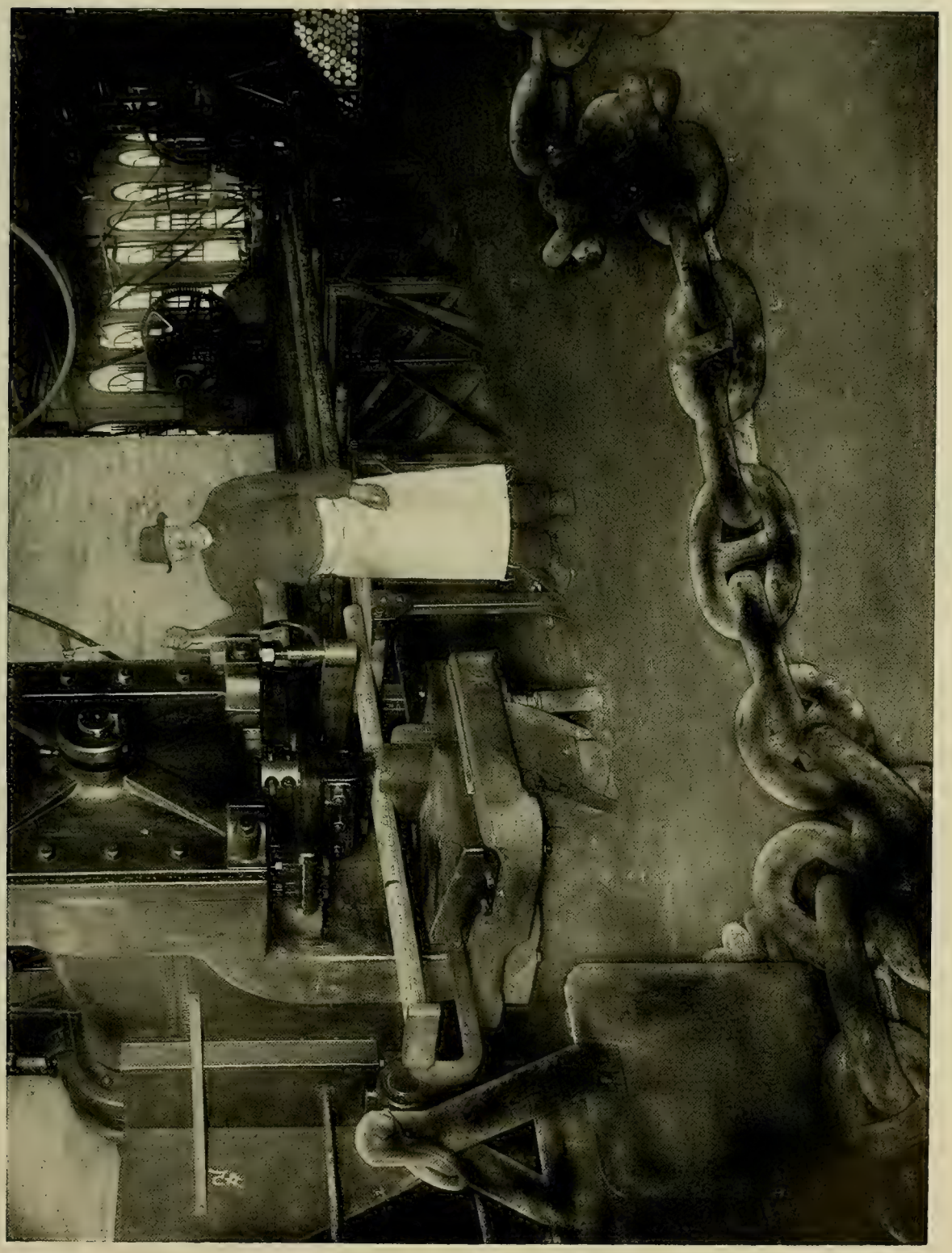


Fig. 10.—Shearing Bars into Bolts.

To illustrate paper on "The Power-Forging of Chain Cables," by Naval Constructor F. G. Coburn, U. S. N., Member.

Fig. 11.—Upsetting the Bolt.

To illustrate paper on "The Power-Forging of Chain Cables," by Naval Constructor F. G. Coburn, U. S. N., Member.

Fig. 12.—Scarfing the Bolt.

To illustrate paper on "The Power-Forging of Chain Cables," by Naval Constructor F. G. Coburn, U. S. N., Member.

Fig. 13.—Bending the Bolt. Ready to Bend.

To illustrate paper on "The Power-Forging of Chain Cables," by Naval Constructor F. G. Coburn, U. S. N., Member.

Fig. 14.—Bending the Bolt. Prying Scarfs Apart.

To illustrate paper on "The Power-Forging of Chain Cables," by Naval Constructor F. G. Coburn, U. S. N., Member.

Fig. 15.—Threading the Preheated Link.

To illustrate paper on "The Power-Forging of Chain Cables," by Naval Constructor F. G. Coburn, U. S. N., Member.

Fig. 16.—First Welding Operation on Dolly Dies.

To illustrate paper on "The Power-Forging of Chain Cables," by Naval Constructor F. G. Coburn, U. S. N., Member.

Fig. 17.—Second Welding Operation, Temporary Plant.

To illustrate paper on "The Power-Forging of Chain Cables," by Naval Constructor F. G. Coburn, U. S. N., Member.

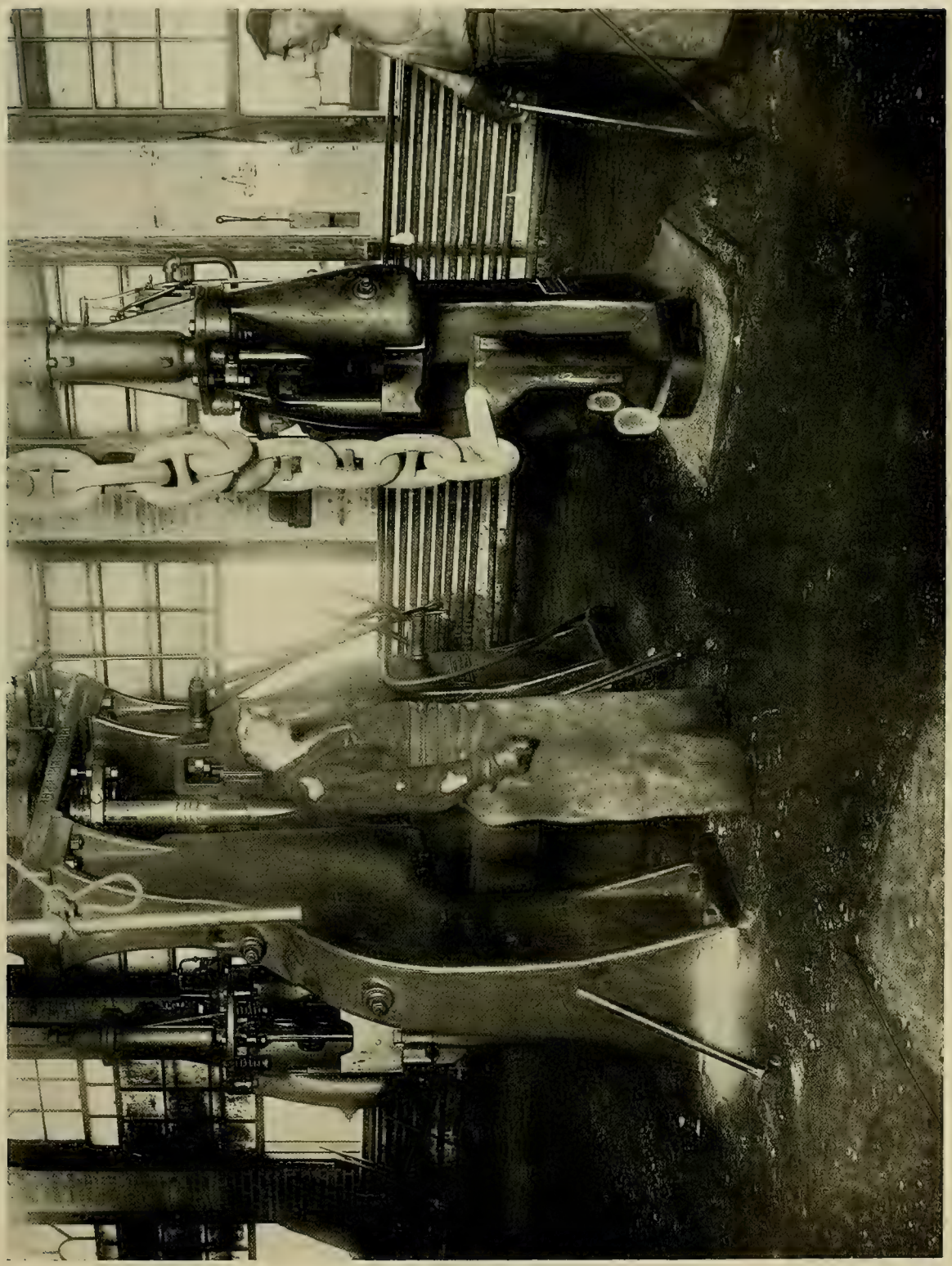
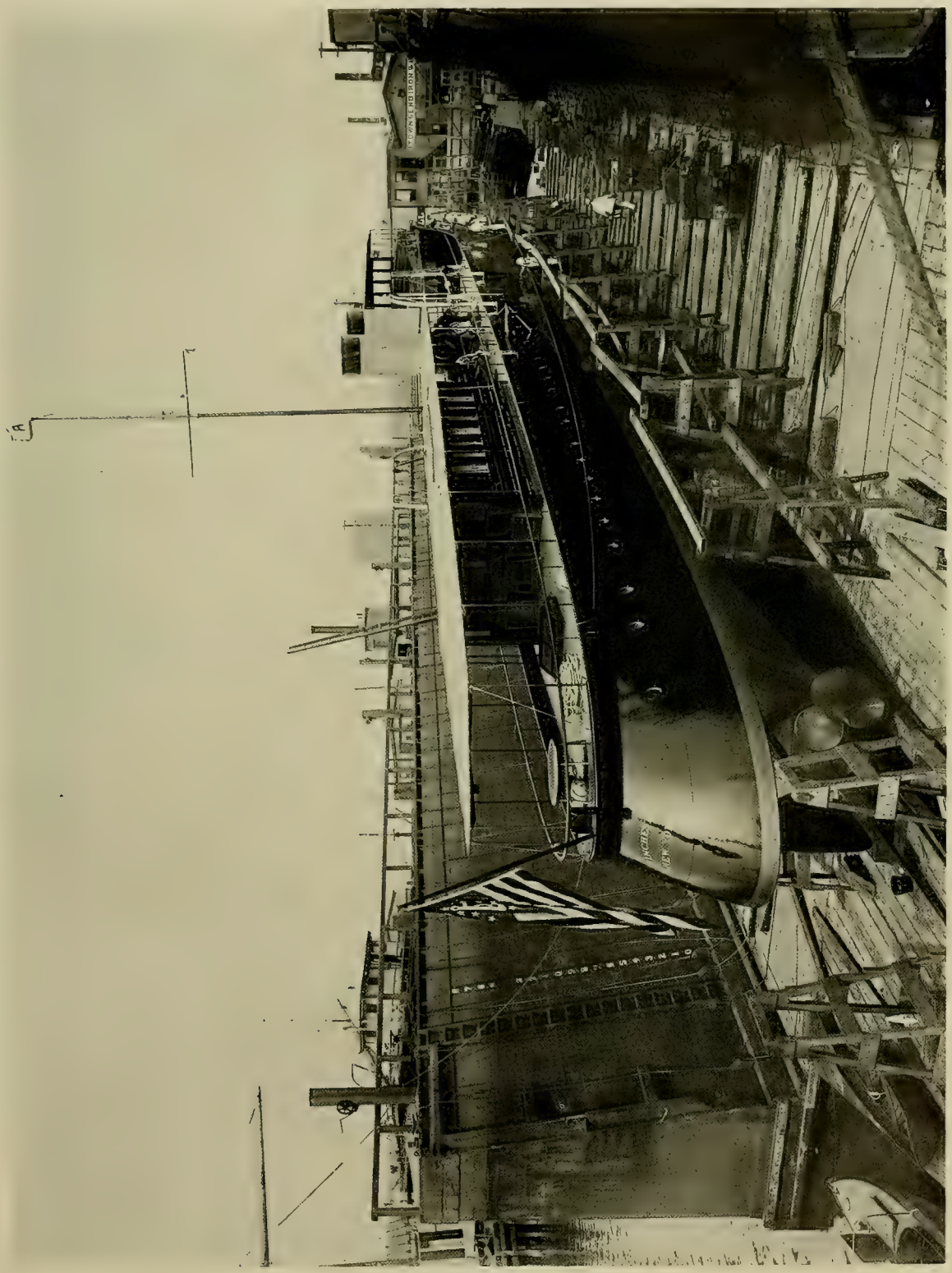


Fig. 18.—New Double Welding Plant.

To illustrate paper on "Description and Trials of the Turbine Steam Yacht Winchester," by E. A. Stevens, Jr., Esq., Member.

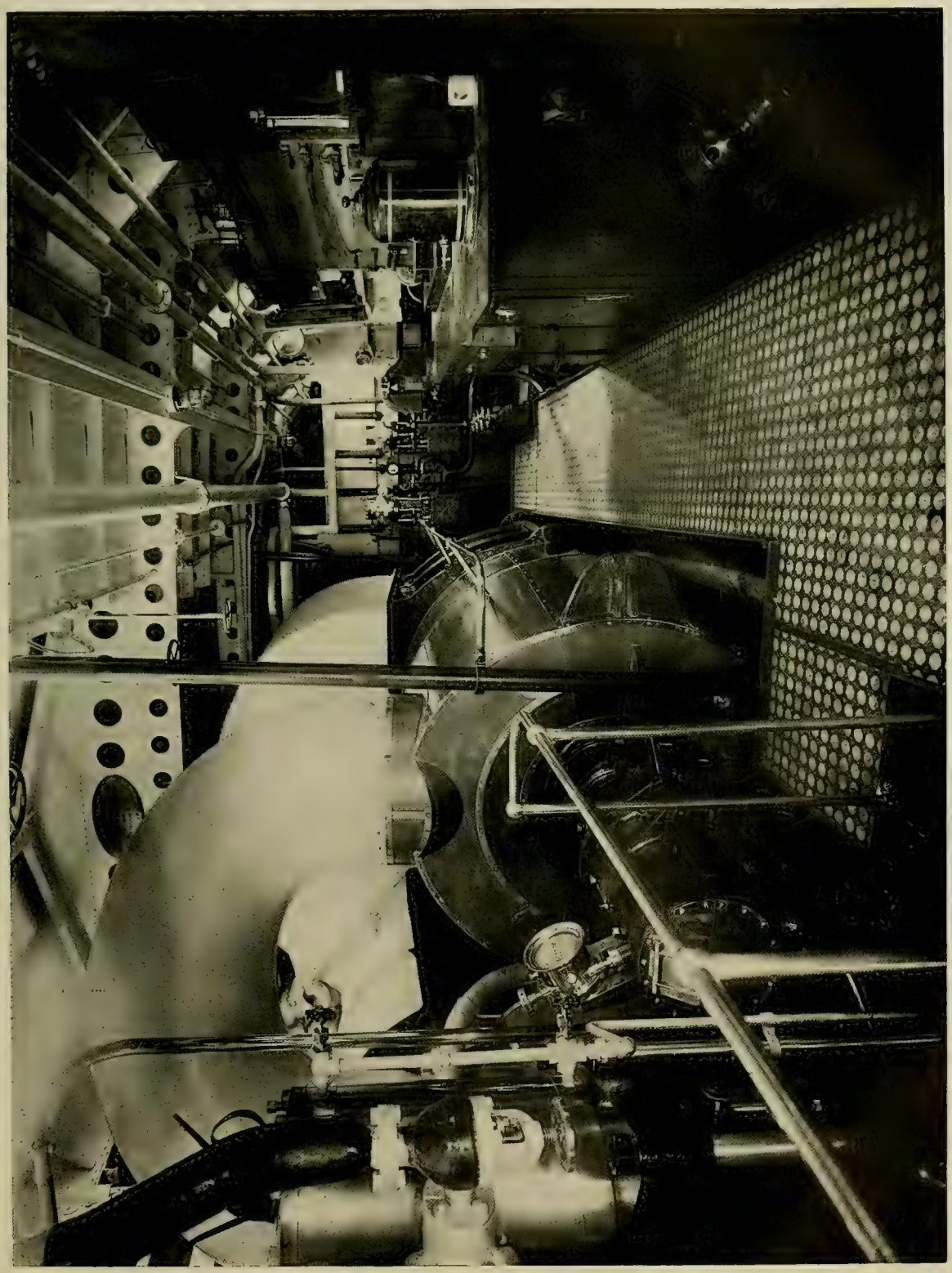


STEAM YACHT WINCHESTER IN DRY DOCK.

To illustrate paper on "Description and Trials of the Turbine Steam Yacht Winchester," by E. A. Stevens, Jr., Esq., Member.

STEAM YACHT WINCHESTER AT ANCHOR.

To illustrate paper on "Description and Trials of the Turbine Steam Yacht Winchester," by E. A. Stevens, Jr., Esq., Member.



STEAM YACHT WINCHESTER—INTERIOR OF ENGINE ROOM.

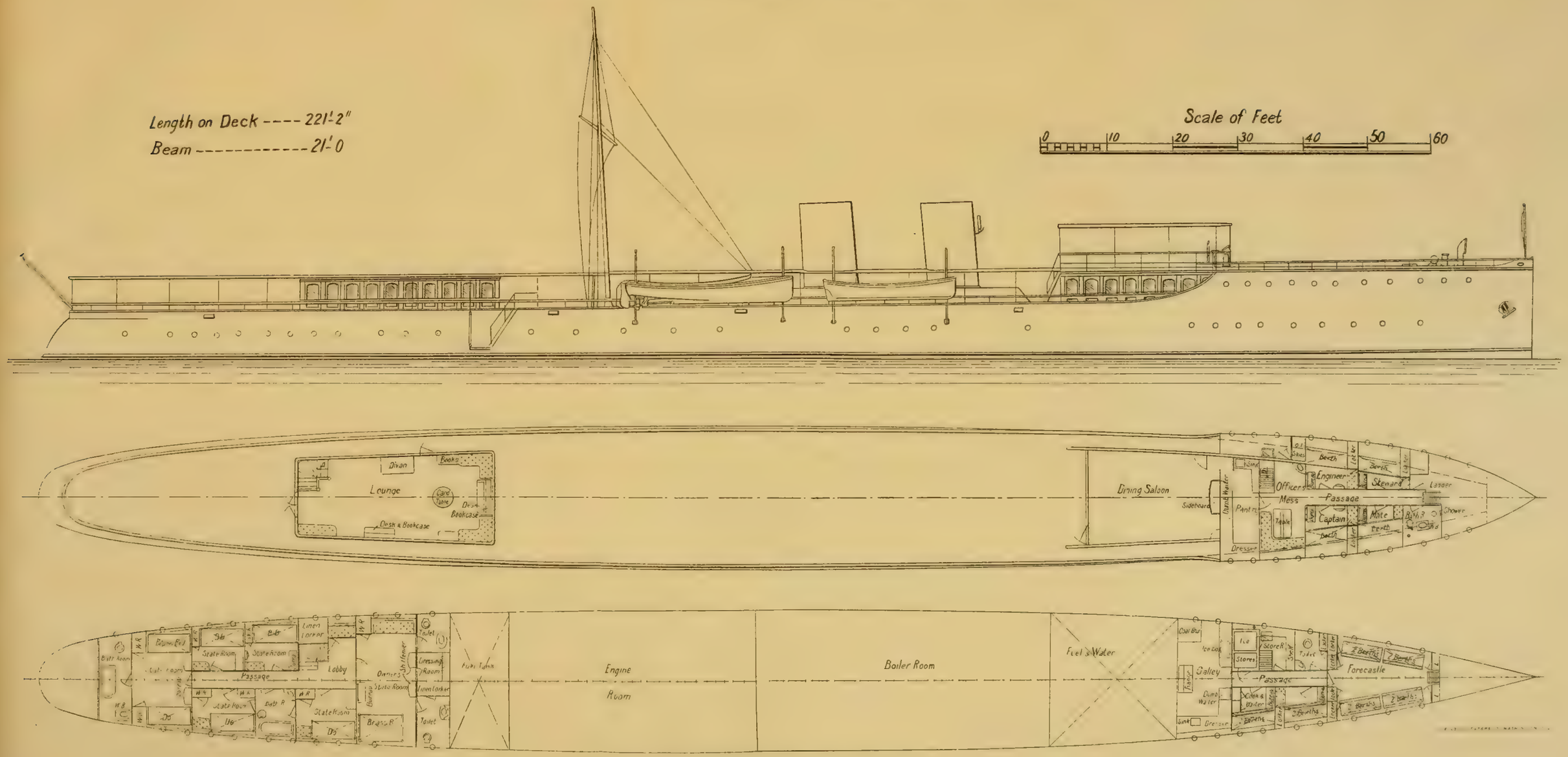
To illustrate paper on "Description and Trials of the Turbine Steam Yacht Winchester," by E. A. Stevens, Jr., Esq., Member.

STEAM YACHT WINCHESTER ON HIGH SPEED RUN, TRIAL TRIP. SHOWING THIN BOW WAVE.

To illustrate paper on "Description and Trials of the Turbine Steam Yacht Winchester," by E. A. Stevens, Jr., Esq., Member.

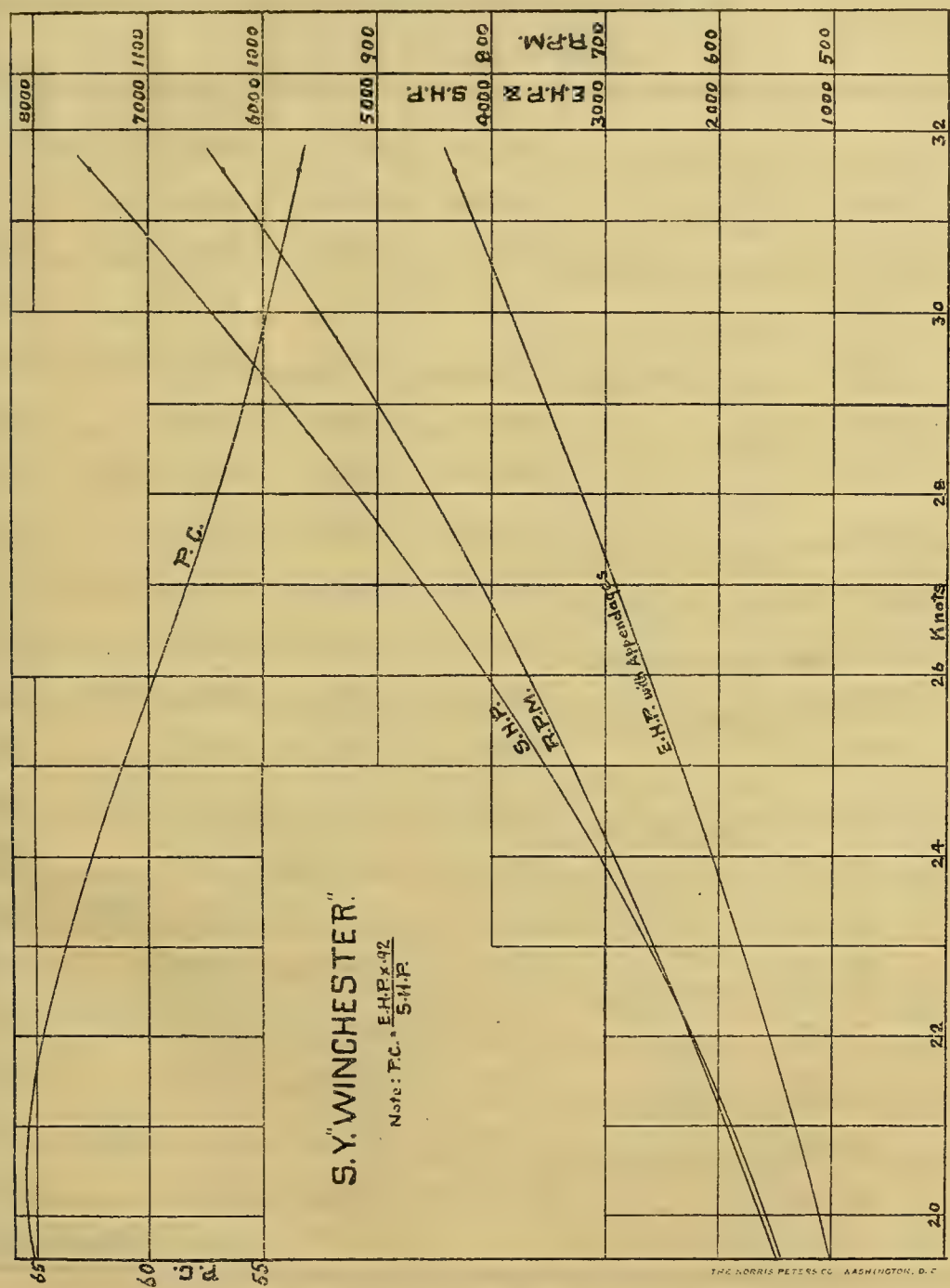
STEAM YACHT WINCHESTER ON HIGH SPEED RUN, TRIAL TRIP. SHOWING WAVE FORMATION.

To illustrate paper on "Description and Trials of the Turbine Steam Yacht Winchester," by E. A. Stevens, Jr., Esq., Member.



STEAM YACHT WINCHESTER—GENERAL ARRANGEMENT PLANS.

To illustrate paper on "Description and Trials of the Turbine Steam Yacht Winchester," by E. A. Stevens, Jr., Esq., Member.



To illustrate paper on "A Theory of Fluid Friction," by William Gatewood, Esq., Member.

TABLE 1

-FUNCTIONS FOR DETERMINING FRICTIONAL RESISTANCE-

V	V^2 or Tanα	H-h	h	b	h x b	Mean Tanα	l	L	l x Mean Tanα
1.00	10000	1.0000	.0000	.0000	.0000				
						.935	.0044		.0041
.95	.9025		.0247	.1662	.0041			.0044	
						.847	.0164		.0139
.90	.8100	.9514	.0486	.3704	.0180			.0208	
						.760	.0359		.0273
.85	.7225		.0718	.6311	.0453			.0567	
						.676	.0638		.0431
.80	.6400	.9057	.0943	.9375	.0884			.1205	
						.596	.1116		.0665
.75	.5625		.1162	1.3333	.1549			.2321	
						.522	.1864		.0973
.70	.4900	.8627	.1373	1.8367	.2522			.4185	
						.453	.3079		.1395
.65	.4225		.1576	2.4852	.3917			.7264	
						.389	.5116		.1990
.60	.3600	.8228	.1772	3.3333	.5907			1.2380	
						.330	.8621		.2845
.55	.3025		.1961	4.4628	.8752			2.1001	
						.275	1.4931		.4106
.50	.2500	.7857	.2143	6.0000	1.2858			3.5932	
						.225	2.6795		.6029
.45	.2025		.2318	8.1481	1.8887			6.2727	
						.180	5.0450		.9081
.40	.1600	.7514	.2486	11.2500	2.7968			11.32	
						.140	10.12		1.4168
.35	.1225		.2647	15.9184	4.2136			21.44	
						.105	22.10		2.3197
.30	.0900	.7200	.2800	23.3333	6.5333			43.54	
						.075	54.30		4.0723
.25	.0625		.2946	36.0000	10.6056			97.84	
						.050	158.1		7.9044
.20	.0400	.6915	.3085	60.0000	18.5100			255.9	
						.030	598.3		17.9493
.15	.0225		.3217	113.333	36.4593			854.2	
						.015	3585.		53.775
.10	.0100	.6658	.3342	270.000	90.234			4439.	
						.006	50700.		304.21
.05	.0025		.3460	1140.000	394.44			55139.	
.00	.0000	.6429	.3571	∞			∞	∞	

Figures are approximate.

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To illustrate paper on "A Theory of Fluid Friction," by William Gatewood, Esq., Member.

FIG. 1

VELOCITY CURVE
IN PIPE
DOTTED LINE SHOWS
EFFECT OF EDDYING

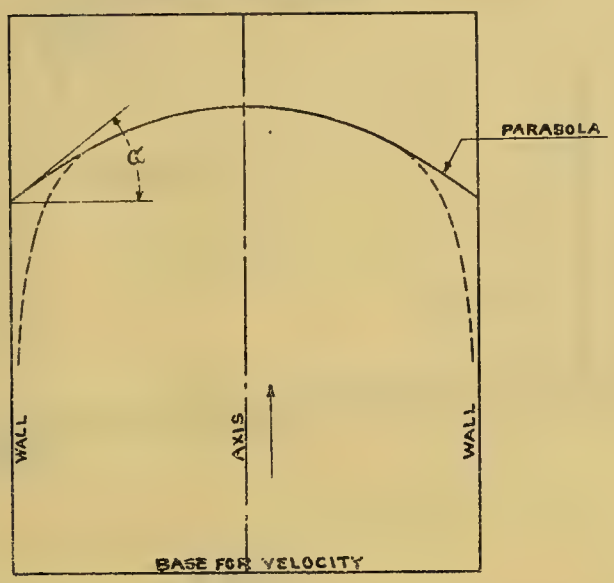
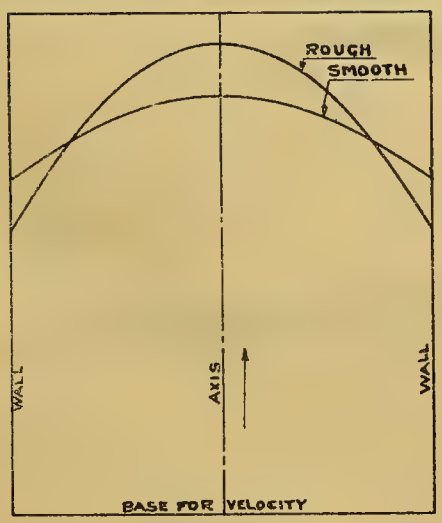


FIG. 2

VELOCITY CURVES
FOR
SMOOTH AND ROUGH PIPES

	SMOOTH	ROUGH
VOLUME OF FLOW	1.000	1.000
MAXIMUM VELOCITY	1.000	1.125.
RESISTANCE	1.000	2.250
COEFFICIENT OF FRICTION	1.000	3.160
VELOCITY HEAD	1.000	1.017



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To illustrate paper on "A Theory of Fluid Friction," by William Gatewood, Esq., Member.

FIG. 3

CHANGE IN DEPTH AT ROUGH LENGTH OF OPEN TROUGH

HEAD DECREASING AS DEPTH INCREASES

$\frac{V^2}{2g} > \frac{Y}{4}$

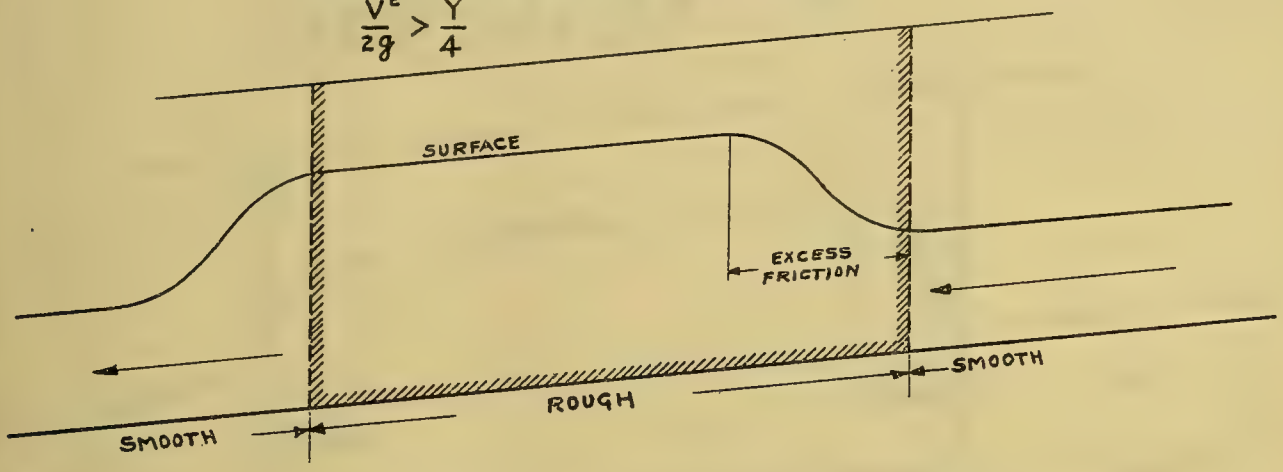
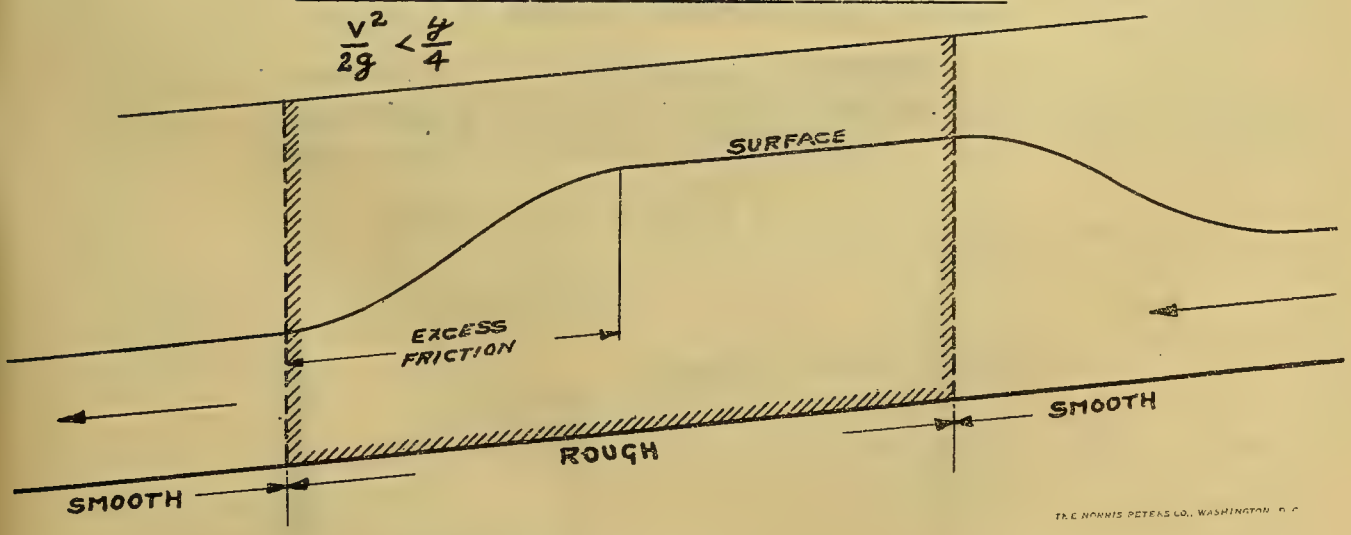


FIG. 4

CHANGE IN DEPTH AT ROUGH LENGTH OF OPEN TROUGH

HEAD INCREASING AS DEPTH INCREASES

$\frac{V^2}{2g} < \frac{y}{4}$



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To illustrate paper on "A Theory of Fluid Friction," by William Gatewood, Esq., Member.

FIG. 5

CHANGE IN DEPTH AT ROUGH LENGTH OF OPEN TROUGH

HEAD FIRST DECREASING AS DEPTH INCREASES AND THEN HEAD INCREASING SLIGHTLY

$$\frac{v^2}{2g} > \frac{y}{4} \text{ AND } \frac{v^2}{2g} + \frac{y}{2} > \frac{V^2}{2g} + \frac{Y}{2}$$

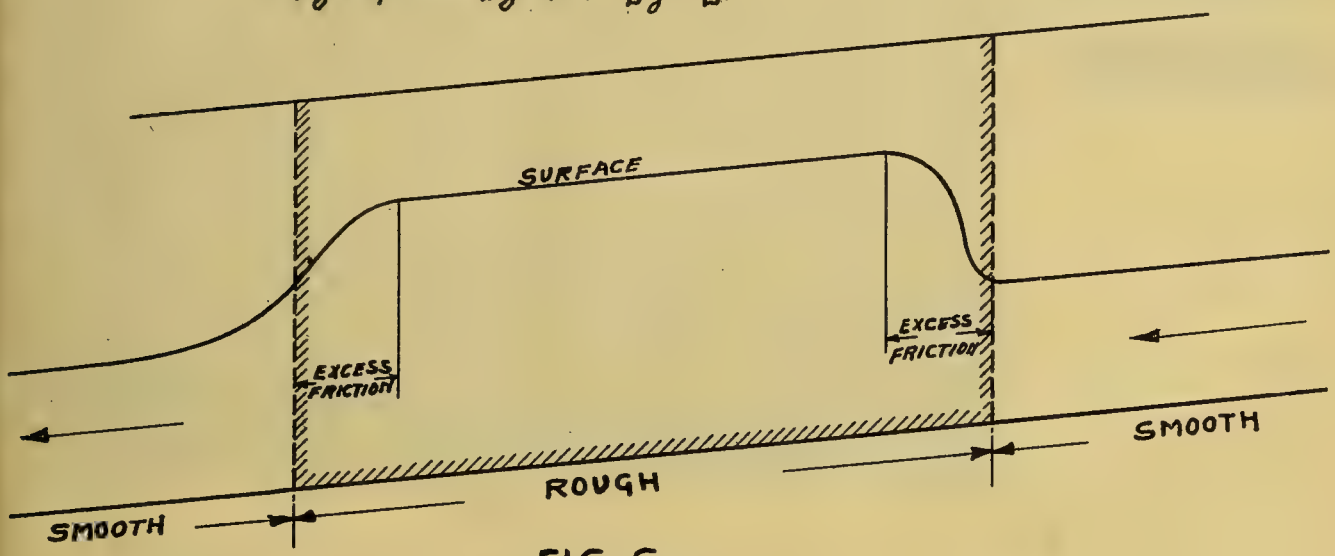
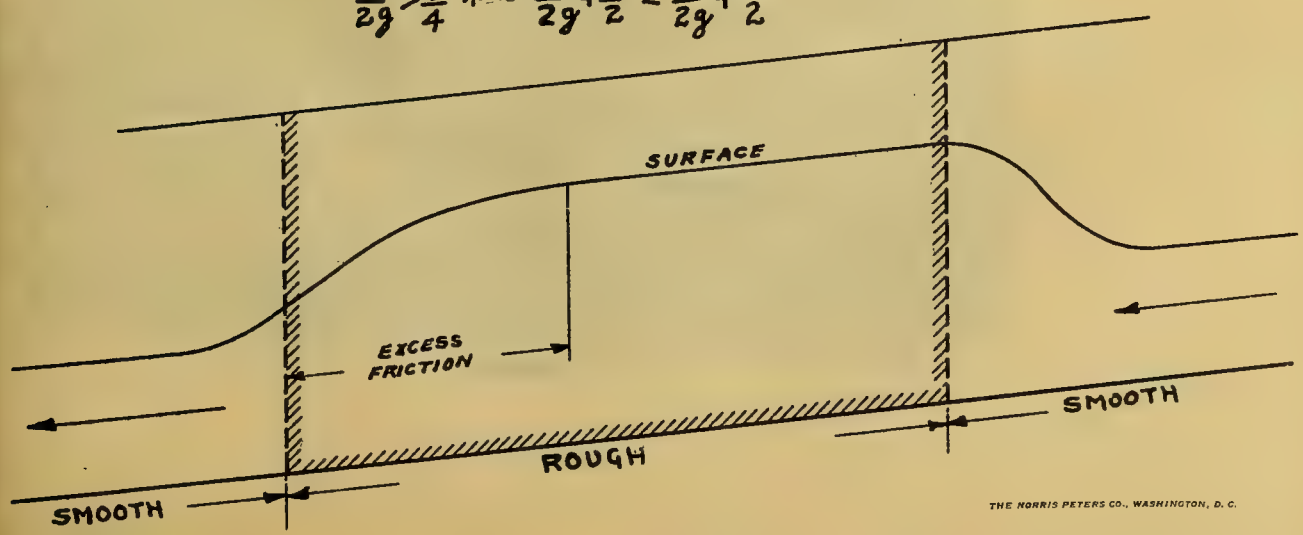


FIG. 6

CHANGE IN DEPTH AT ROUGH LENGTH OF OPEN TROUGH

HEAD FIRST DECREASING AS DEPTH INCREASES AND THEN HEAD INCREASING TO GREATER THAN INITIAL HEAD

$$\frac{v^2}{2g} > \frac{y}{4} \text{ AND } \frac{v^2}{2g} + \frac{y}{2} < \frac{V^2}{2g} + \frac{Y}{2}$$



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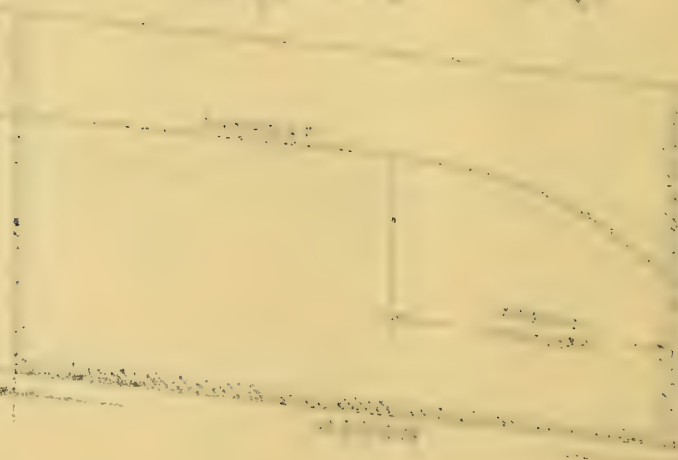

To illustrate paper on "A Theory of Fluid Friction," by William Gatewood, Esq., Member.

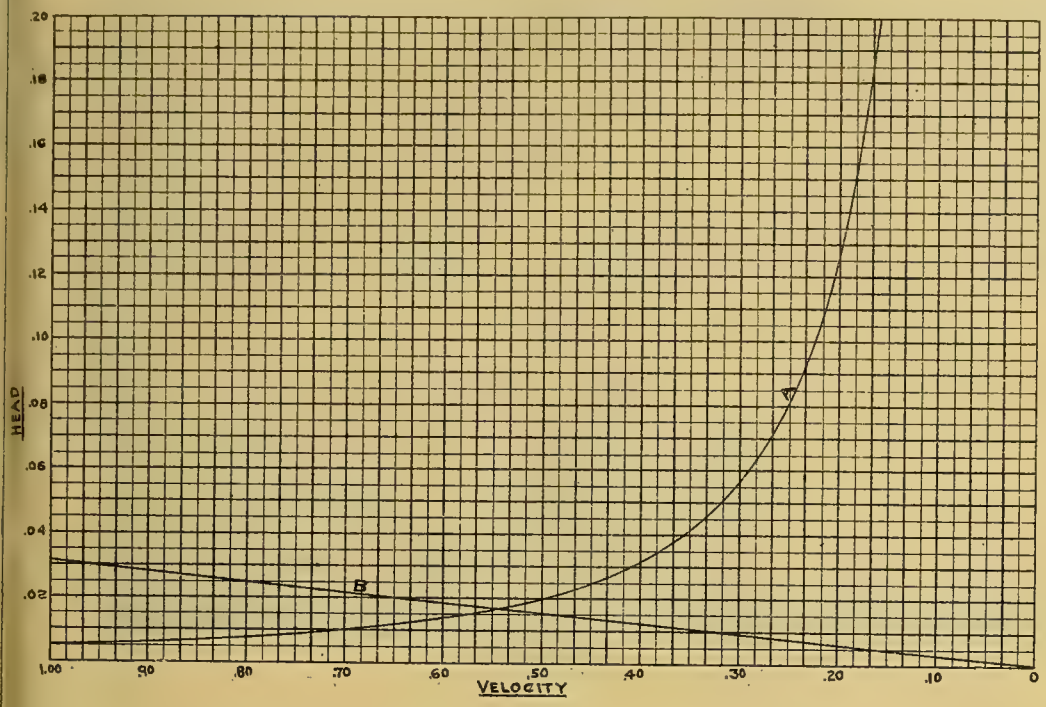

FIG. 7

A—INCREASE IN POSITION HEAD OF A LAMINA OF WATER FOR EACH FOOT OF DEPTH FOR EACH PERCENT LOSS OF VELOCITY

B—LOSS OF VELOCITY HEAD OF A LAMINA OF WATER FOR EACH PERCENT LOSS OF VELOCITY INITIAL VELOCITY 10 F.S.

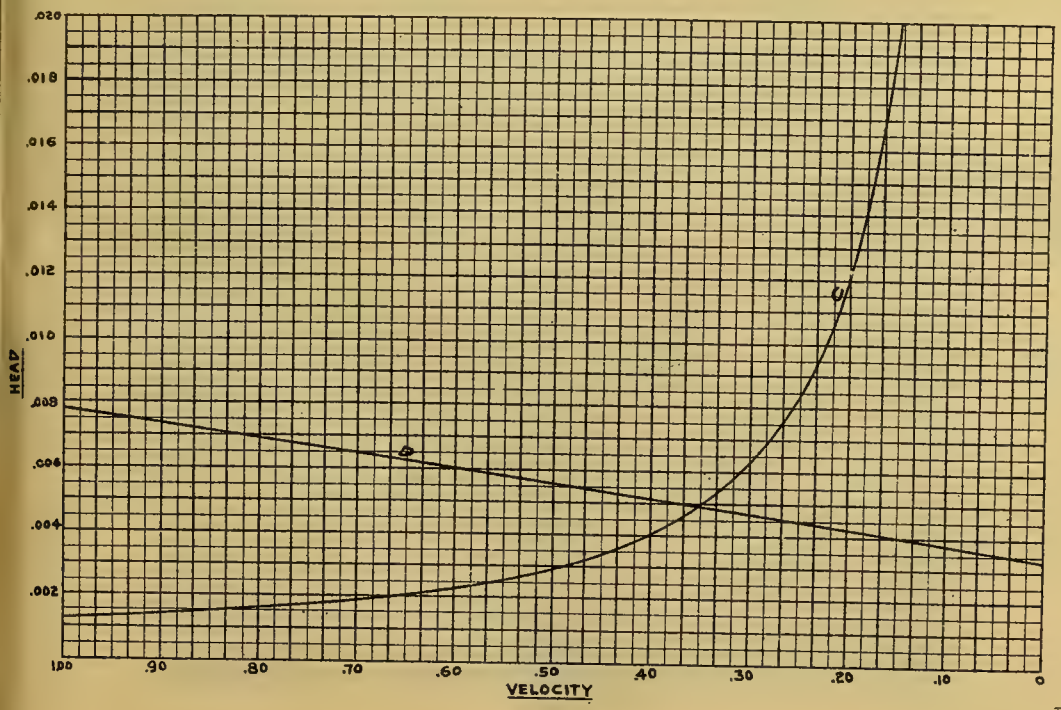

FIG. 8

C—INCREASE IN POSITION HEAD OF WHOLE WIDTH OF WAKE FOR EACH FOOT OF DEPTH FOR EACH PERCENT LOSS OF VELOCITY

D—LOSS OF VELOCITY HEAD OF WHOLE WIDTH OF WAKE FOR EACH PERCENT LOSS OF VELOCITY INITIAL VELOCITY 10 F.S.

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To illustrate paper on "A Theory of Fluid Friction," by William Gatewood, Esq., Member.

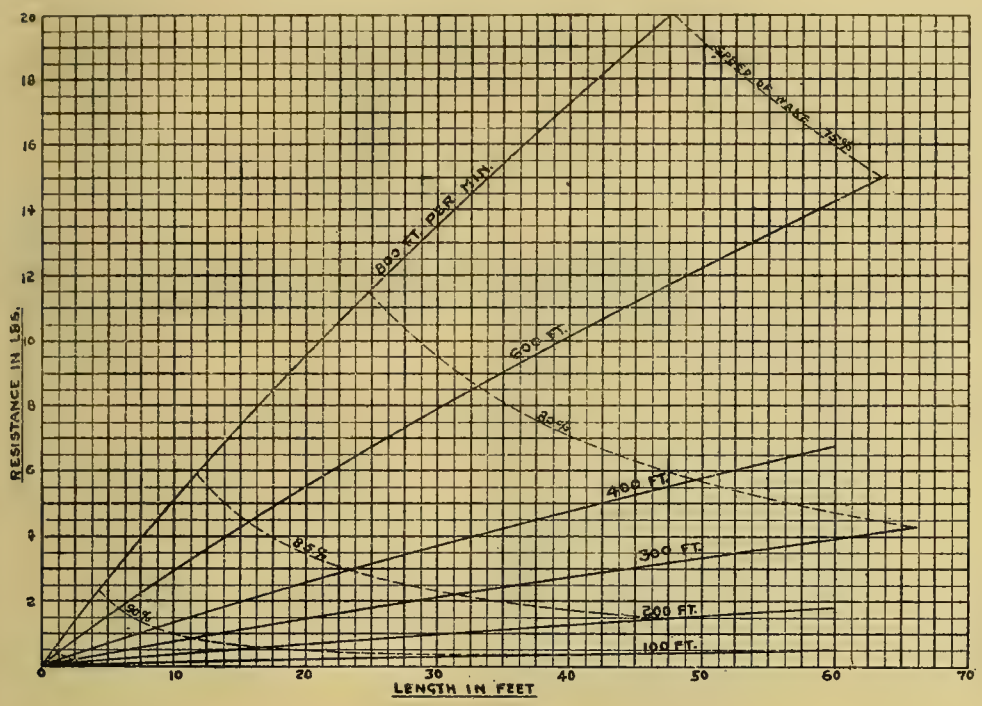

FIG. 9
FRICTIONAL RESISTANCE
STRIP ONE FT. WIDE
BY THEORY
f = .003538
F = .03538
TAN α = 10 AT 10 F.S.

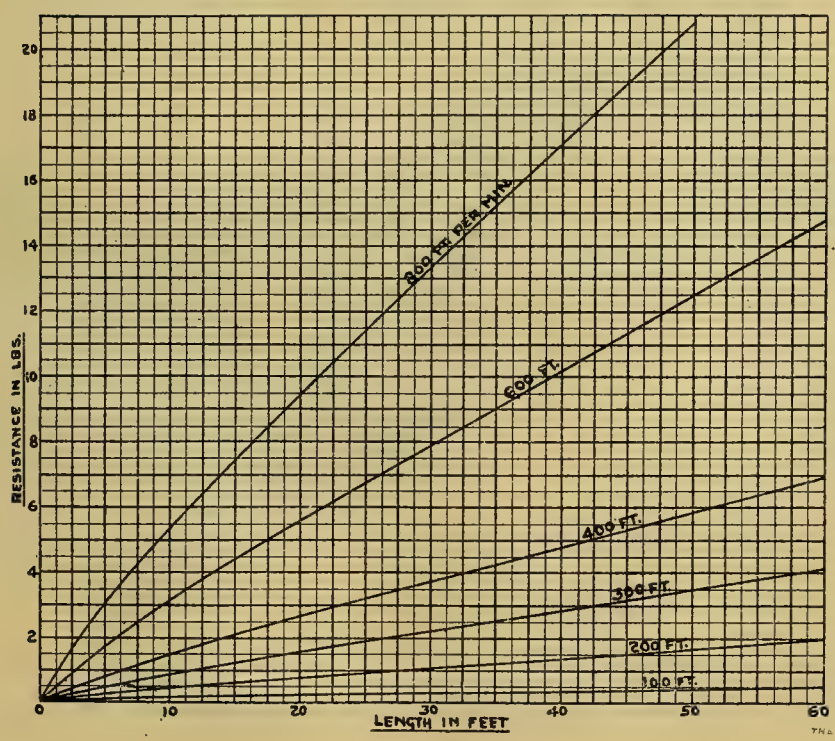

FIG. 10
FRICTIONAL RESISTANCE
STRIP ONE FT. WIDE
SHELLAC SURFACE
DATA FROM W. FROUDE

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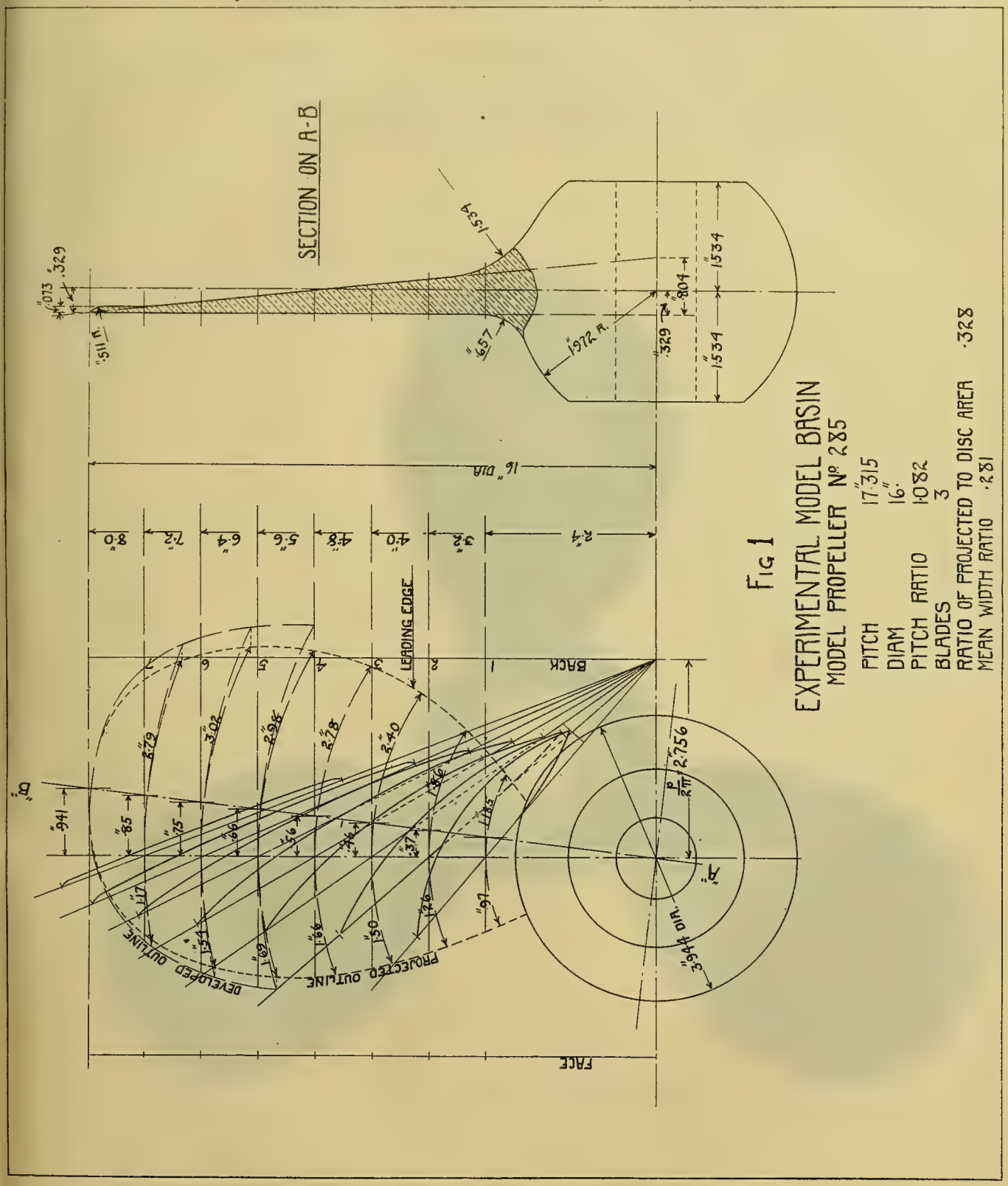
To illustrate paper on "Notes from the Model Basin," by Naval Constructor William McEntee, U. S. N., Member.



To illustrate paper on "Notes from the Model Basin," by Naval Constructor William McEntee, U. S. N., Member.

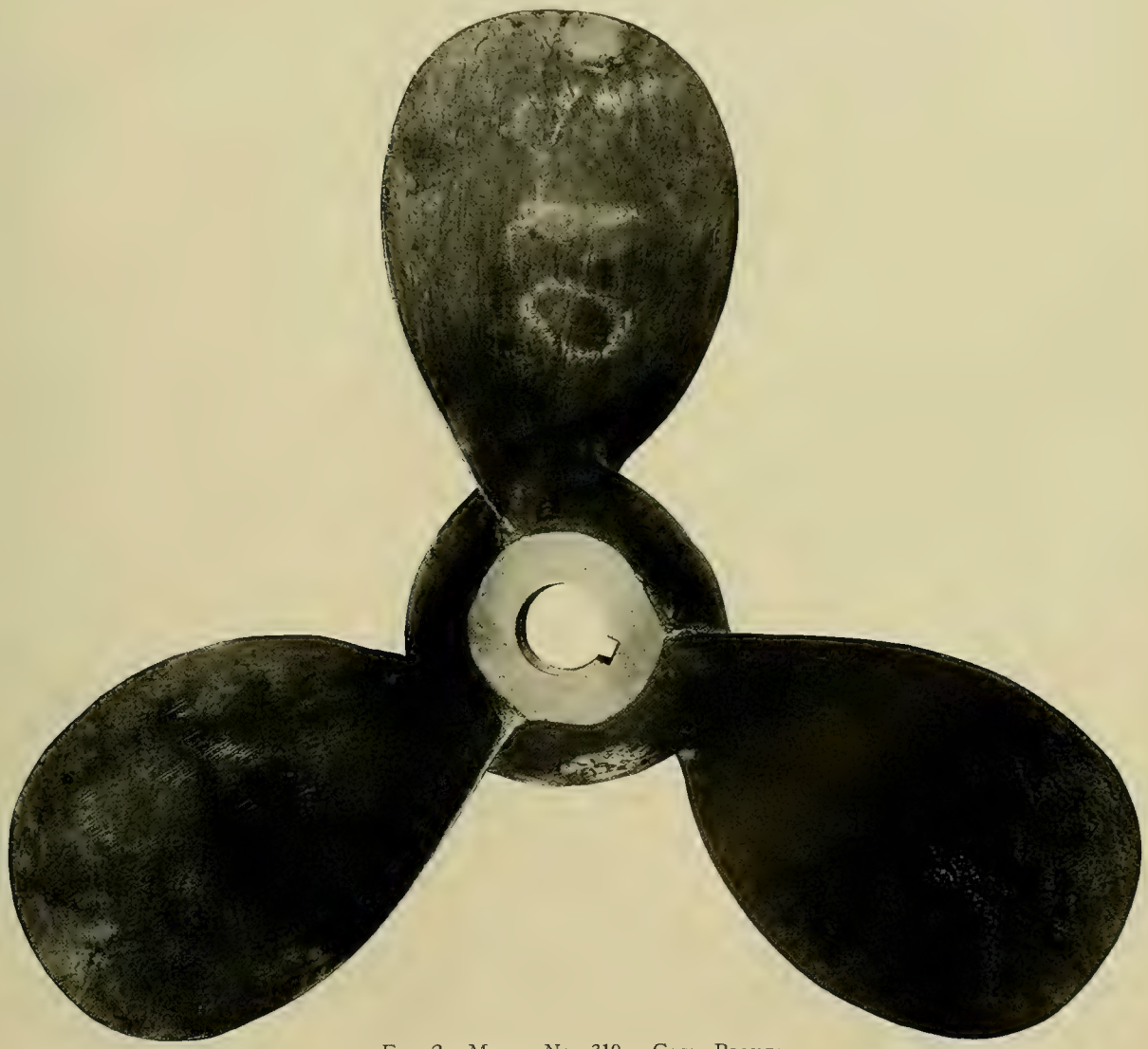


Fig 2.—Model No. 310. Cast Bronze.

To illustrate paper on "Notes from the Model Basin," by Naval Constructor William McEntee, U. S. N., Member.

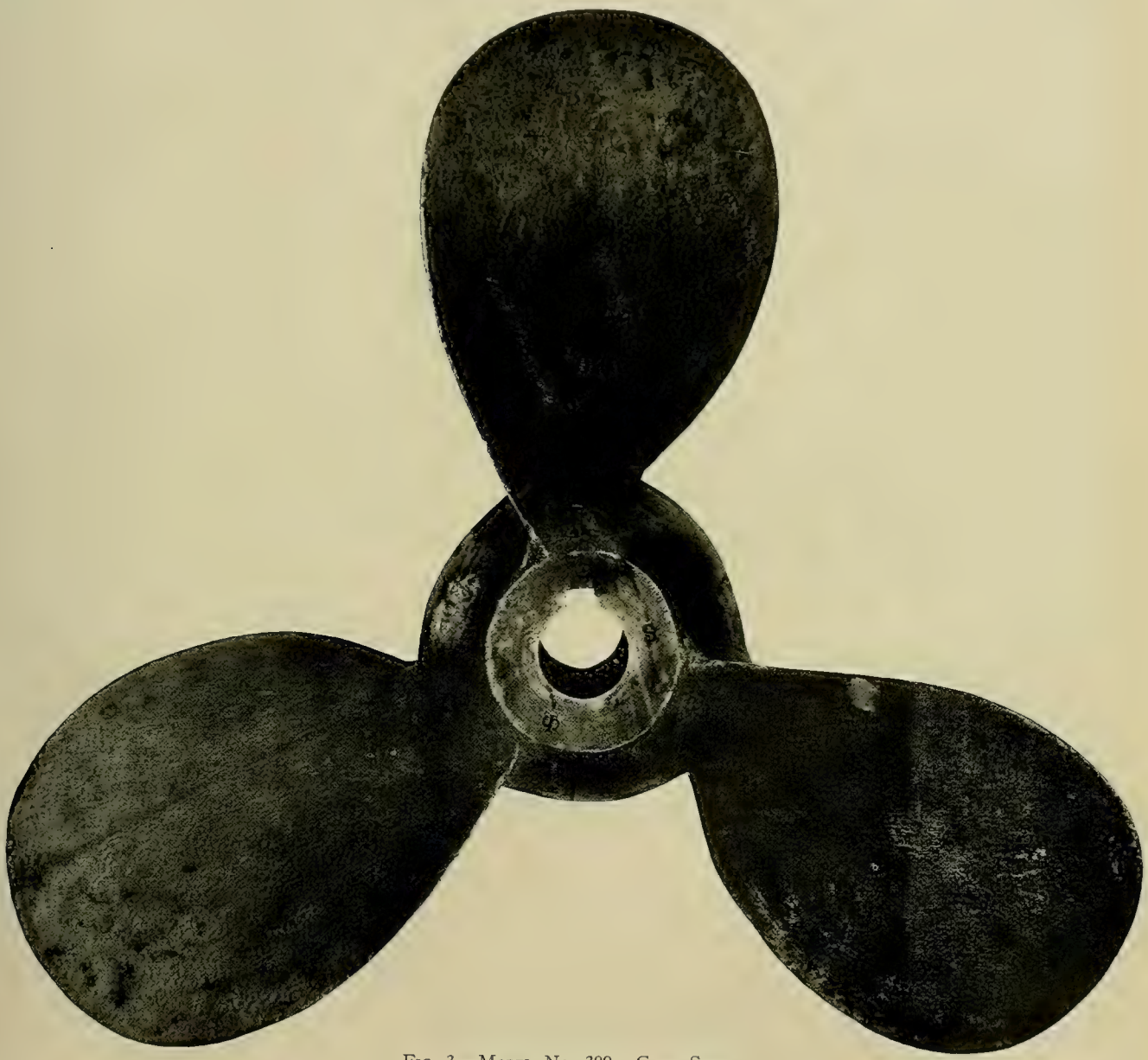


Fig. 3.—Model No. 309. Cast Steel.

To illustrate paper on "Notes from the Model Basin," by Naval Constructor William McEntee, U. S. N., Member.

Fig. 4.—Model No. 308. Cast Iron.

To illustrate paper on "Notes from the Model Basin," by Naval Constructor William McEntee, U. S. N., Member.

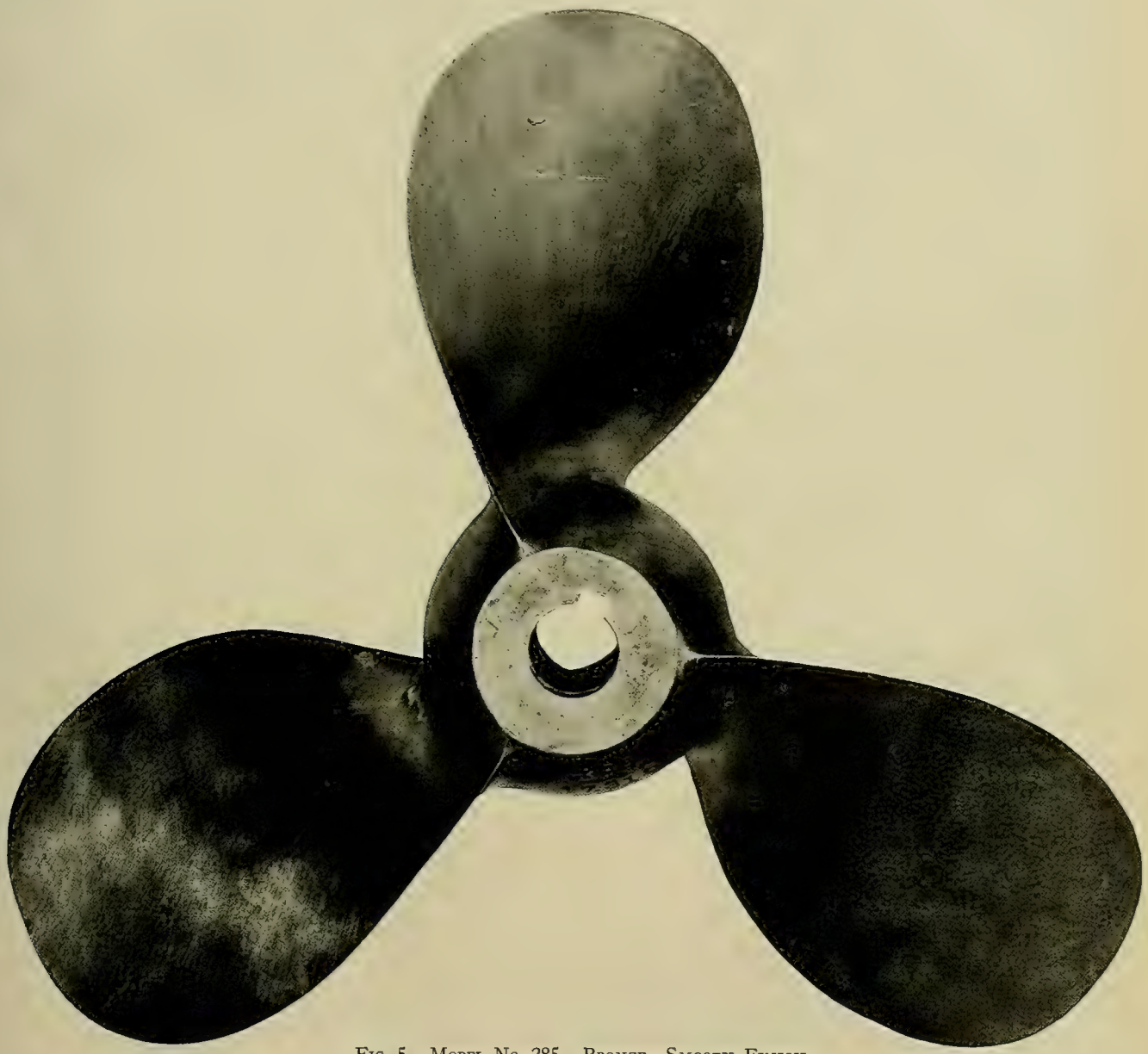


Fig. 5.—Model No. 285. Bronze—Smooth Finish.

To illustrate paper on "Notes from the Model Basin," by Naval Constructor William McEntee, U. S. N., Member.

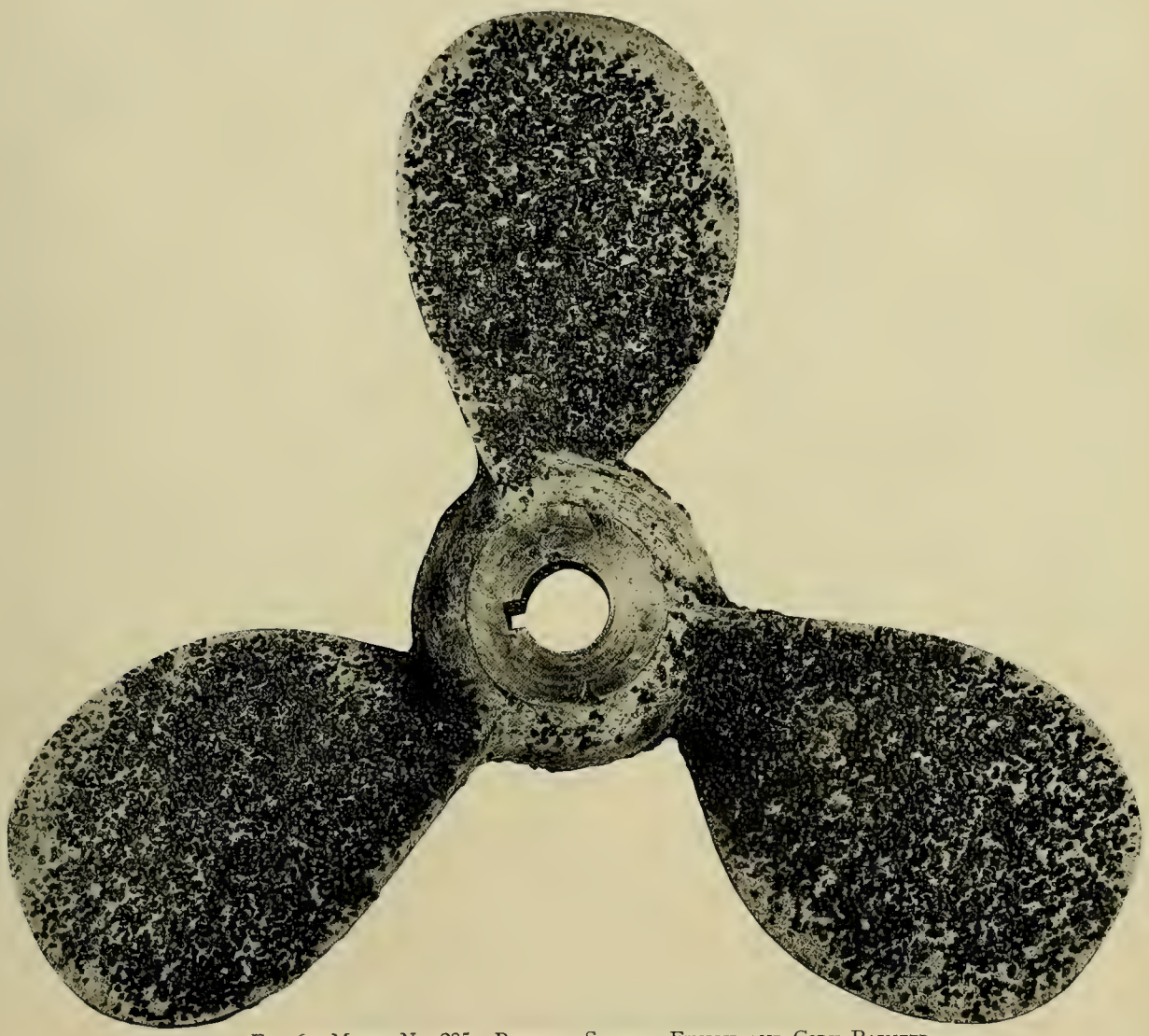
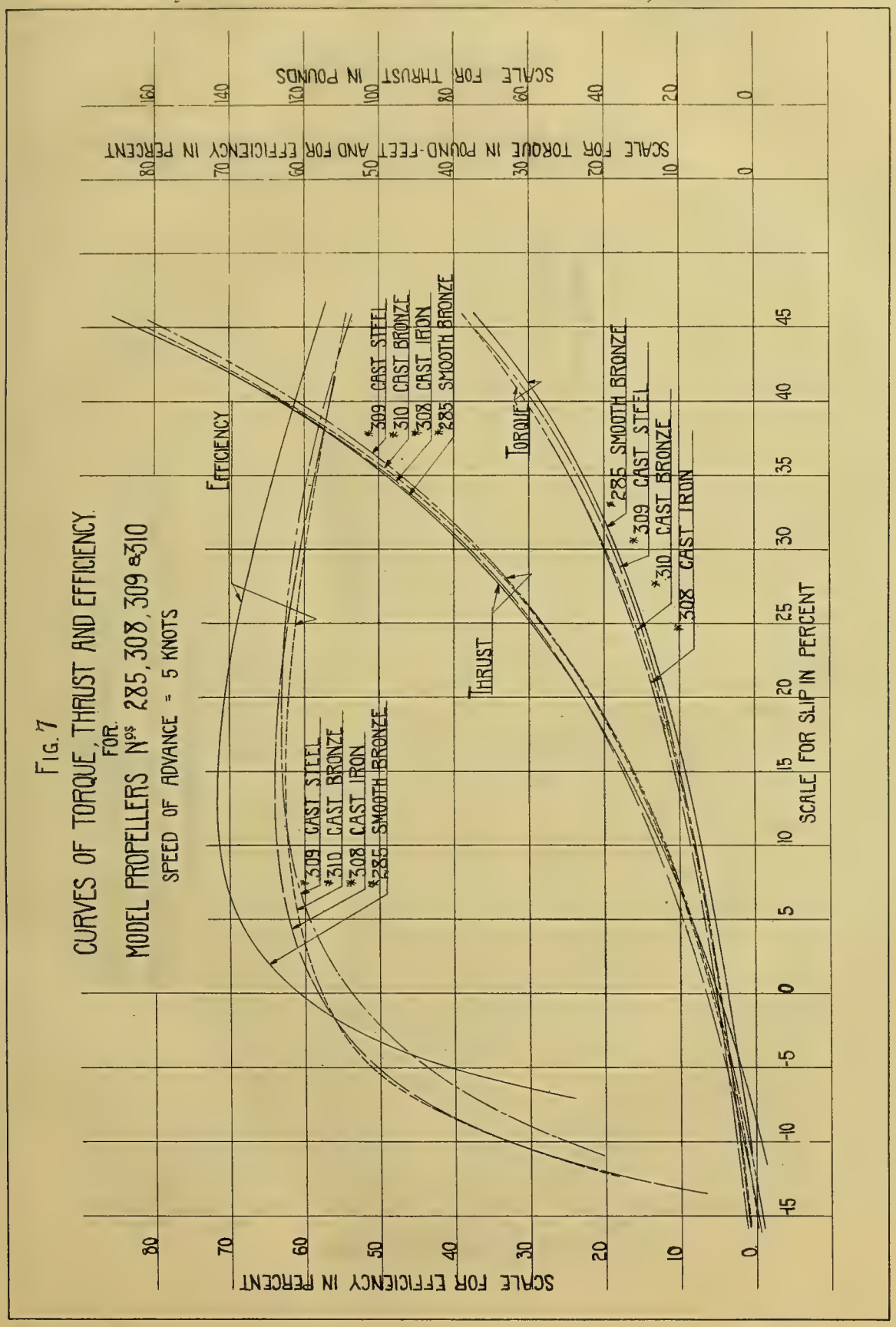


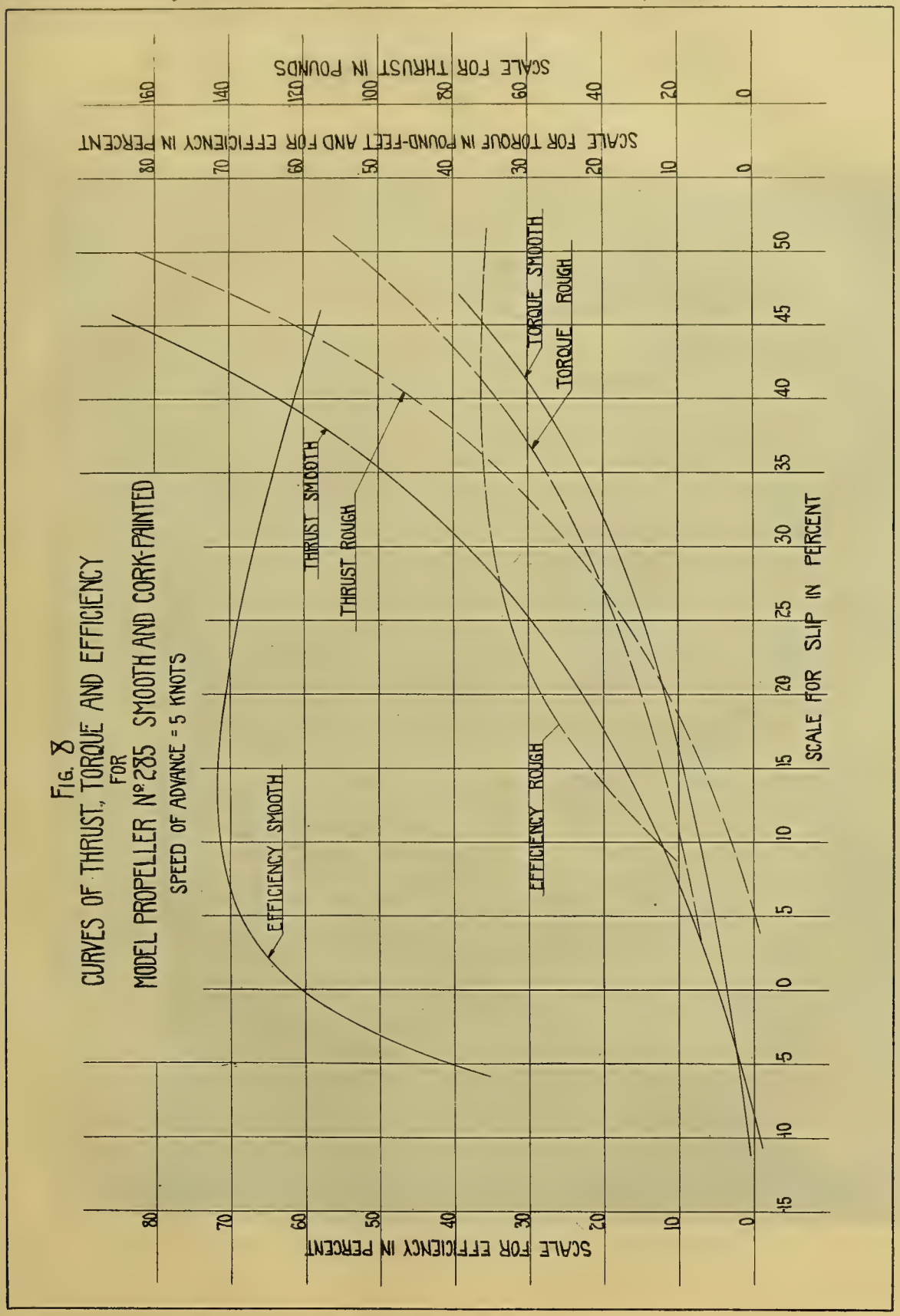
Fig. 6.—Model No. 285. Bronze—Smooth Finish and Cork Painted.

To illustrate paper on "Notes from the Model Basin," by Naval Constructor William McEntee, U. S. N., Member.



THE NORRIS PETERS CO., WASHINGTON D.C.

To illustrate paper on "Notes from the Model Basin," by Naval Constructor William McEntee, U. S. N., Member.



THE HORRIS PRINTERS CO., WASHINGTON, D.C.

To illustrate paper on "Notes from the Model Basin," by Naval Constructor William McEntee, U. S. N., Member.

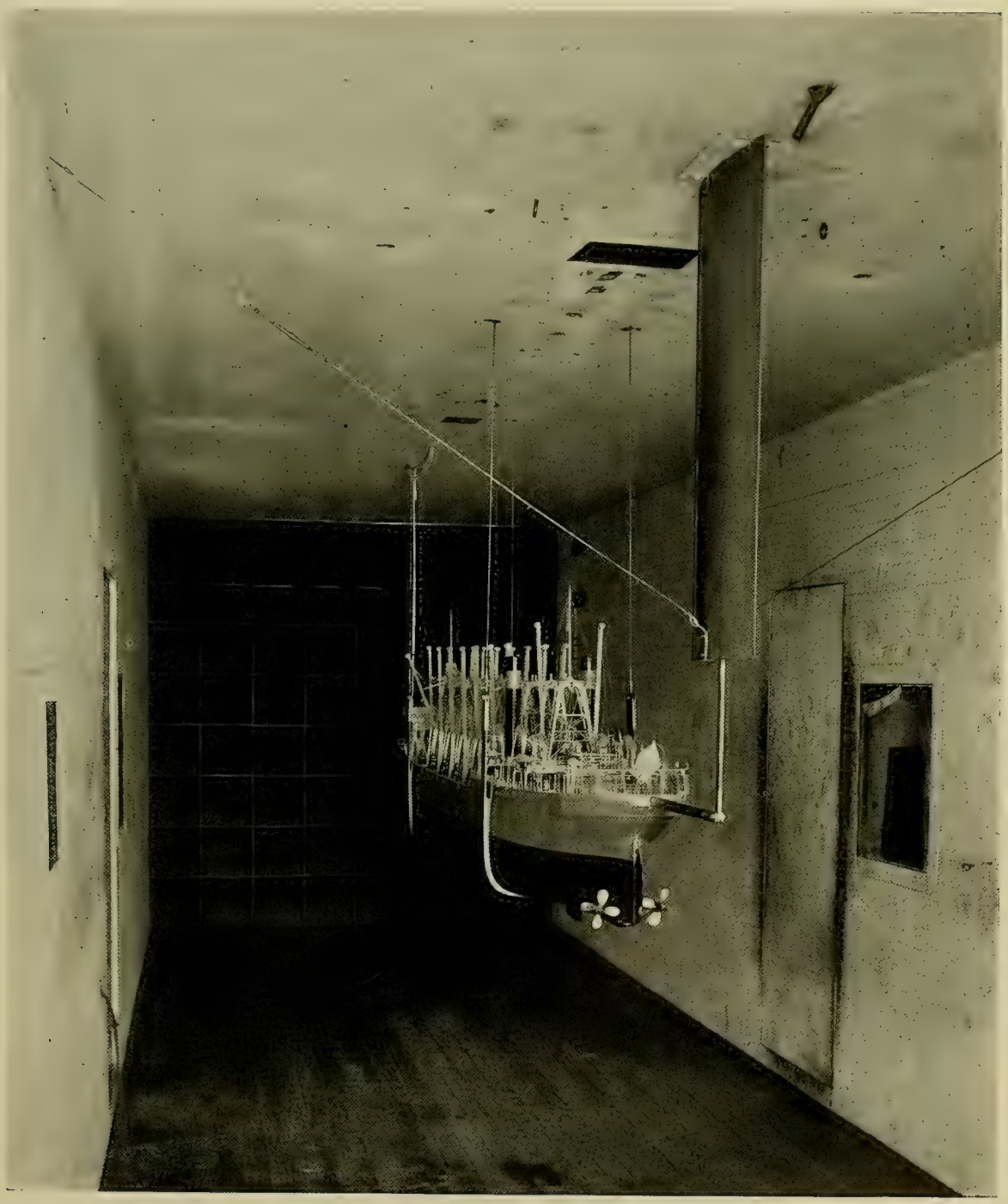


FIG. 9.—STERN VIEW OF MODEL SUSPENDED IN WIND TUNNEL.

To illustrate paper on "Notes from the Model Basin," by Naval Constructor William McEntee, U. S. N., Member.

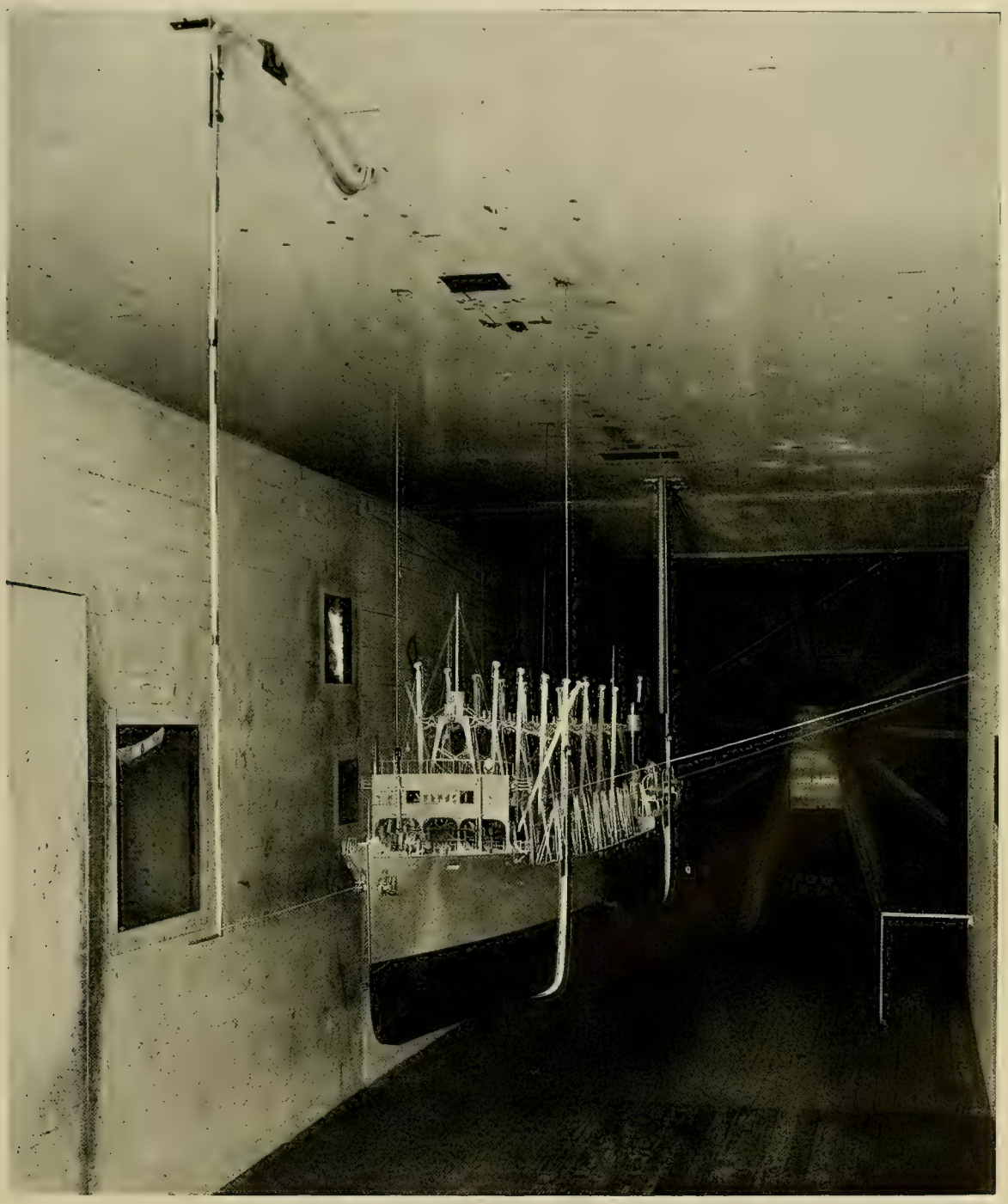
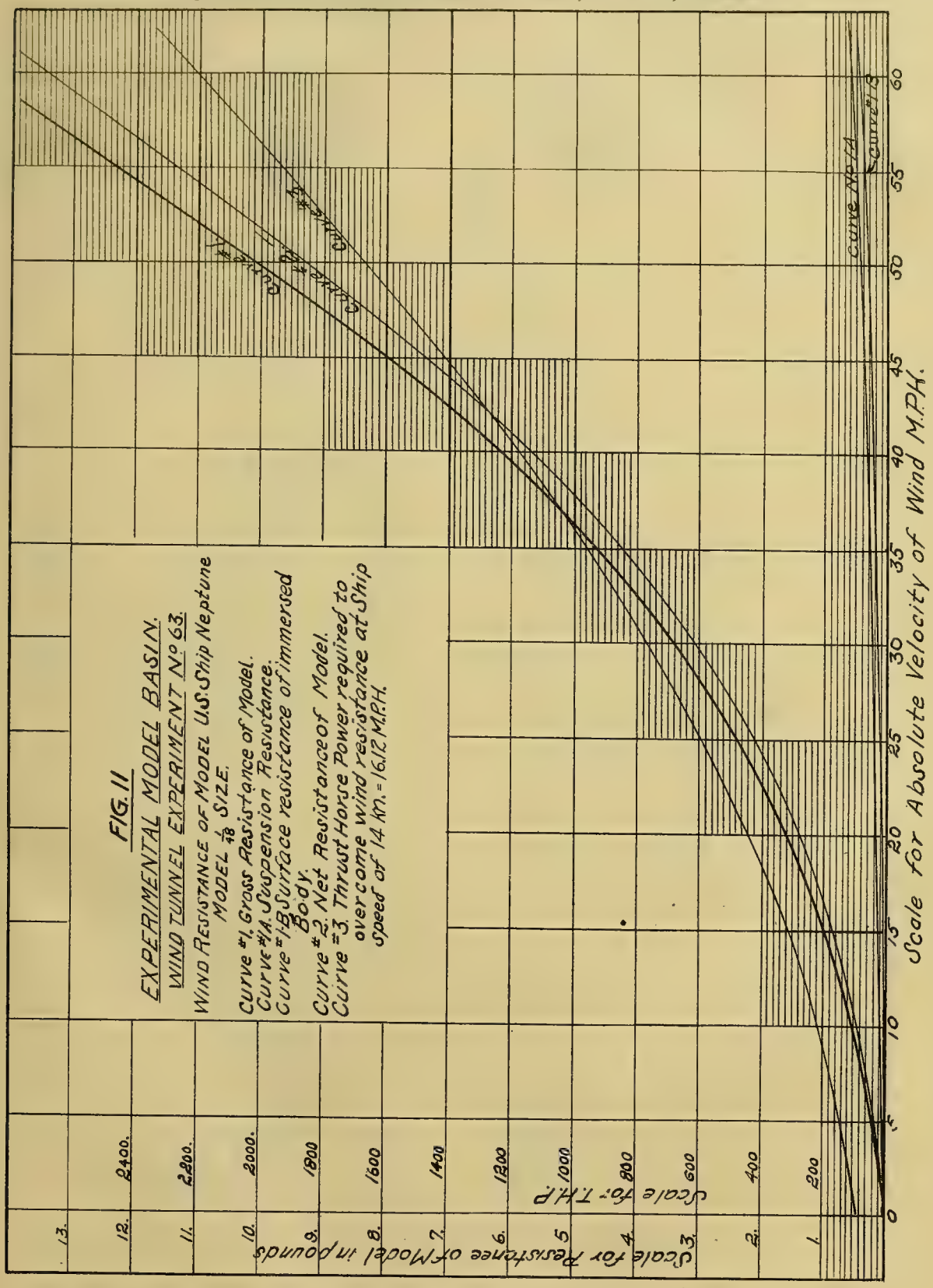
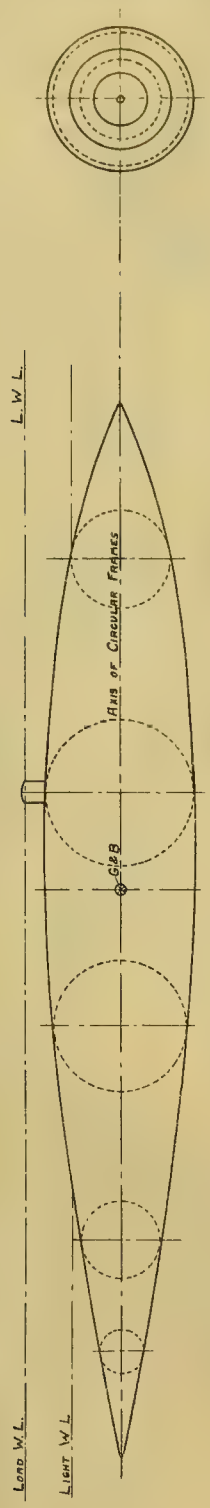


Fig. 10.—Bow View of Model Suspended in Wind Tunnel.

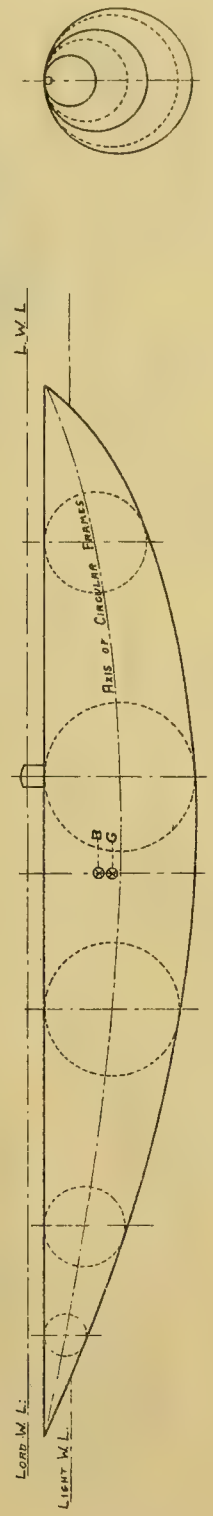
To illustrate paper on "Notes from the Model Basin," by Naval Constructor William McEntee, U. S. N., Member.



To illustrate discussion by Simon Lake, Esq., on paper entitled "On the Suitability of Current Design of Submarines to the Needs of the United States Navy," by Captain W. L. Rodgers, U. S. N., Associate.



Cigar Shaped Form of Hull Described, G & B, Both on Axis of Hull – No Stability.



Hull With Rising Axis, G & B, Both Above Center of Midship Frame, is Stable and Will Resist Same External Pressure as Cigar Shaped Form.

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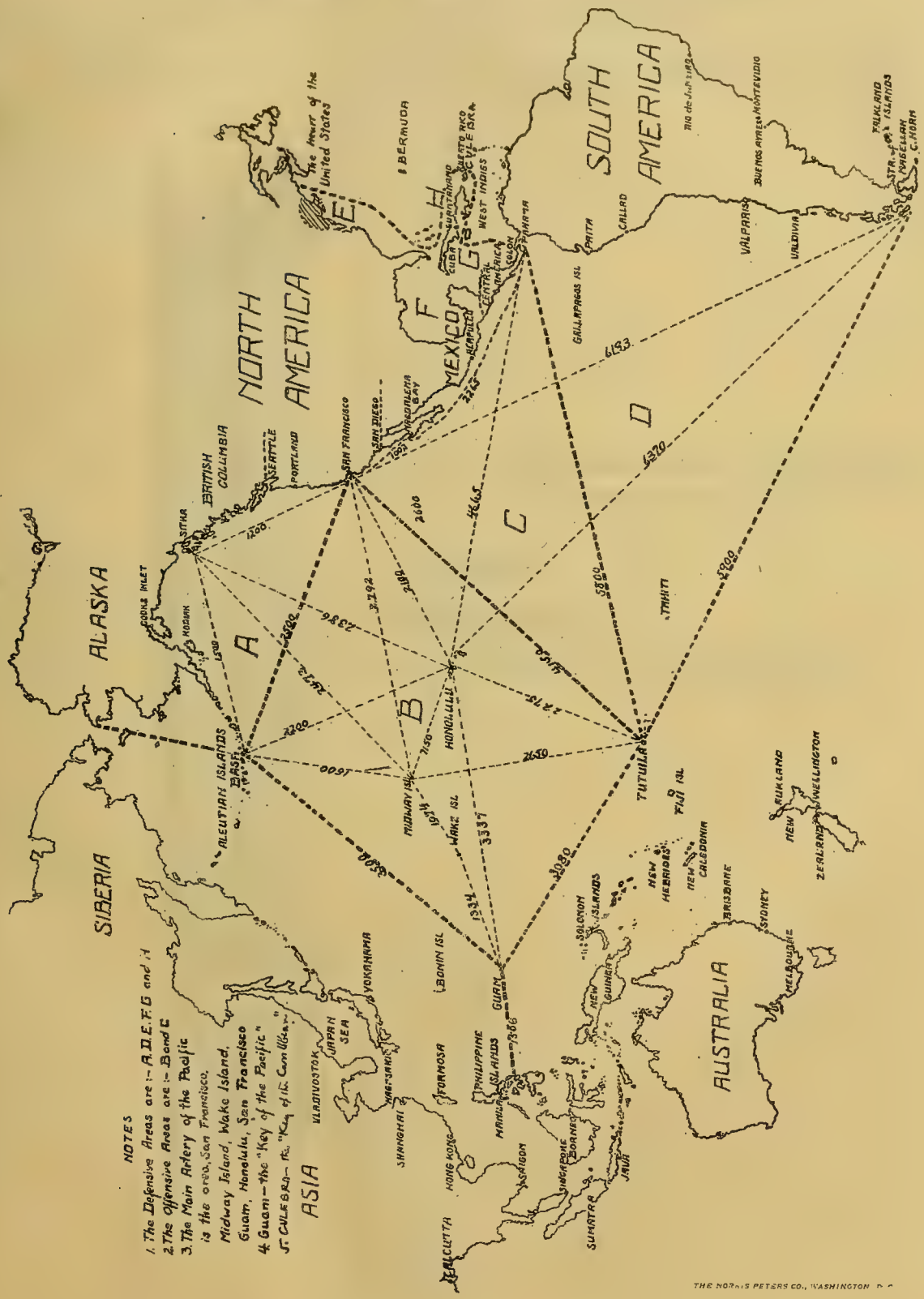
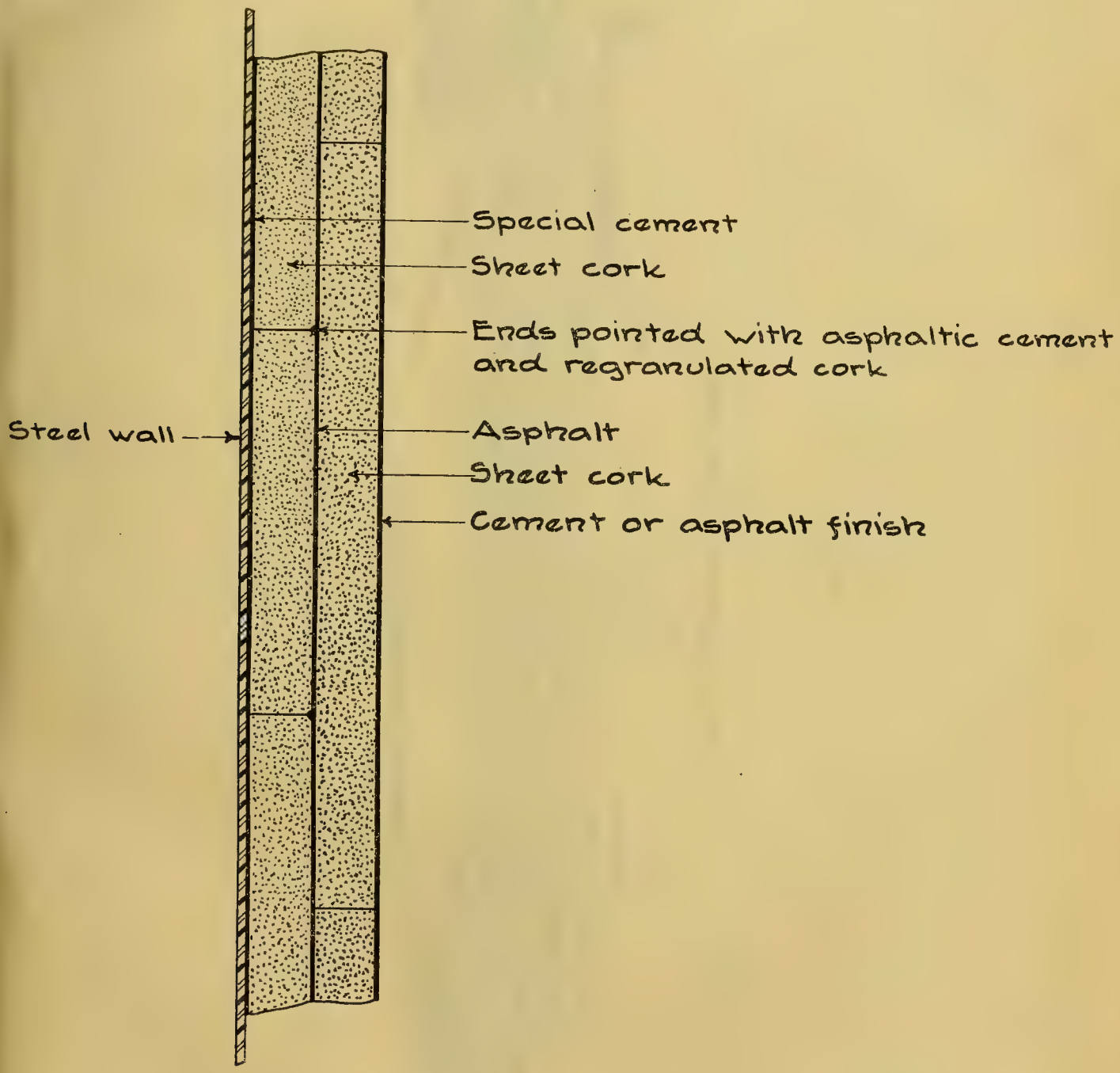
To illustrate paper on "Naval Stations and Naval Bases," by Captain A. P. Niblack, U. S. N., Vice-President.



To illustrate paper on "Refrigeration and Refrigerator Insulation on Board Ship," by Robert F. Massa, Esq.



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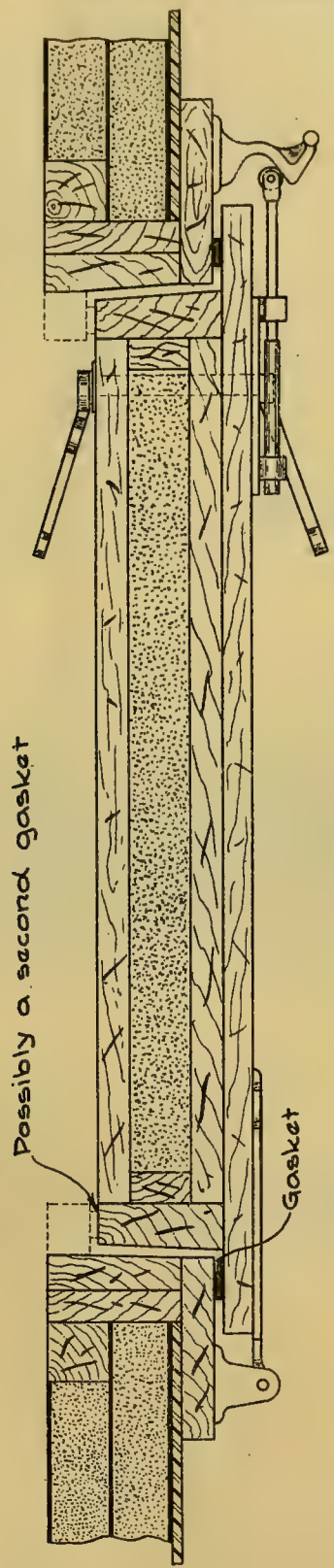
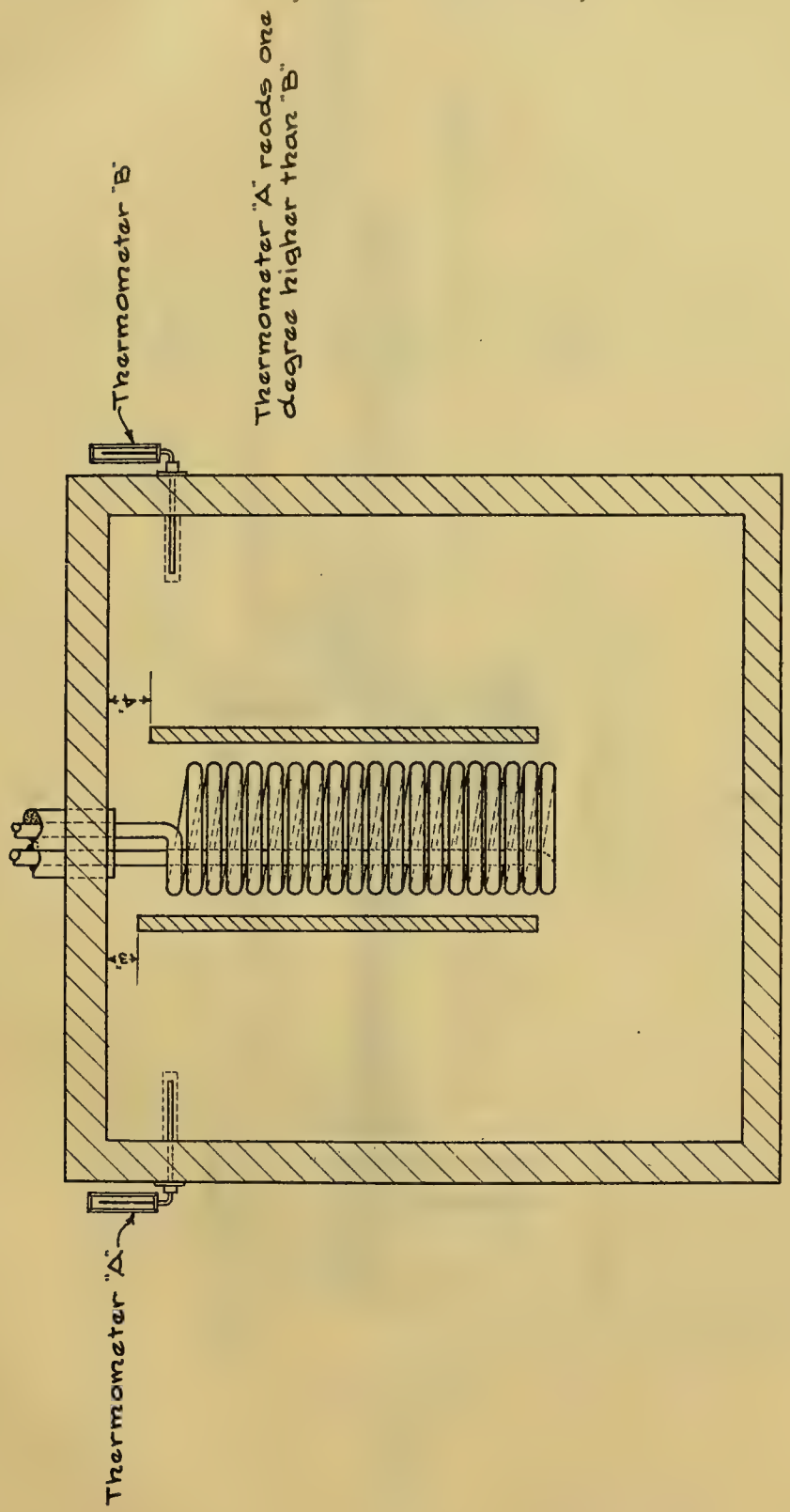
To illustrate paper on "Refrigeration and Refrigerator Insulation on Board Ship," by Robert F. Massa, Esq.



PLAN OF REFRIGERATOR DOOR.

To illustrate paper on "Refrigeration and Refrigerator Insulation on Board Ship," by Robert F. Massa, Esq.



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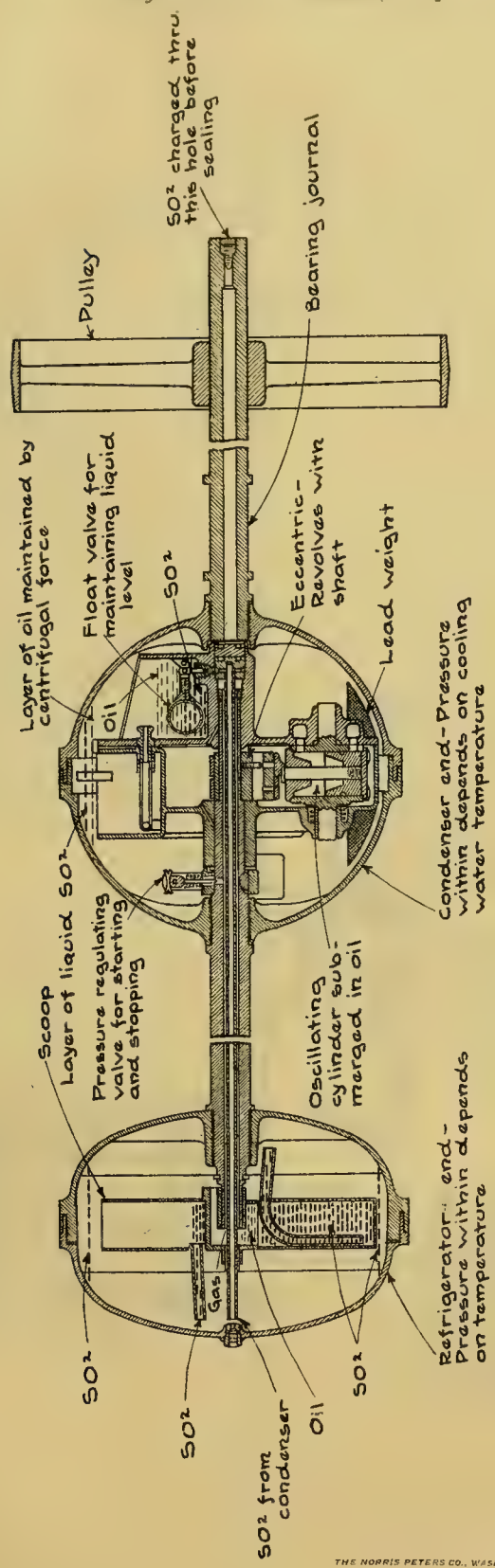
To illustrate paper on "Refrigeration and Refrigerator Insulation on Board Ship," by Robert F. Massa, Esq.



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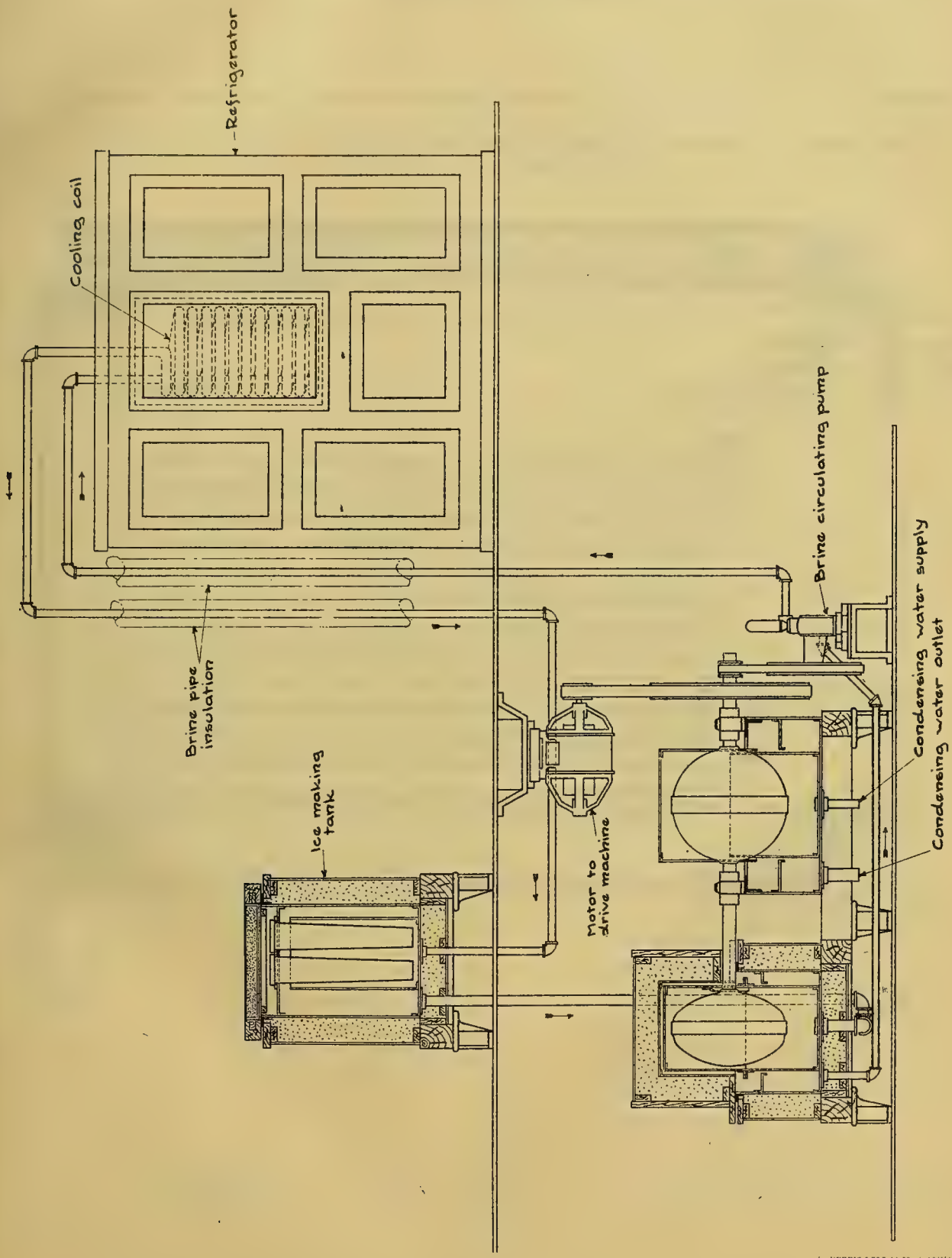
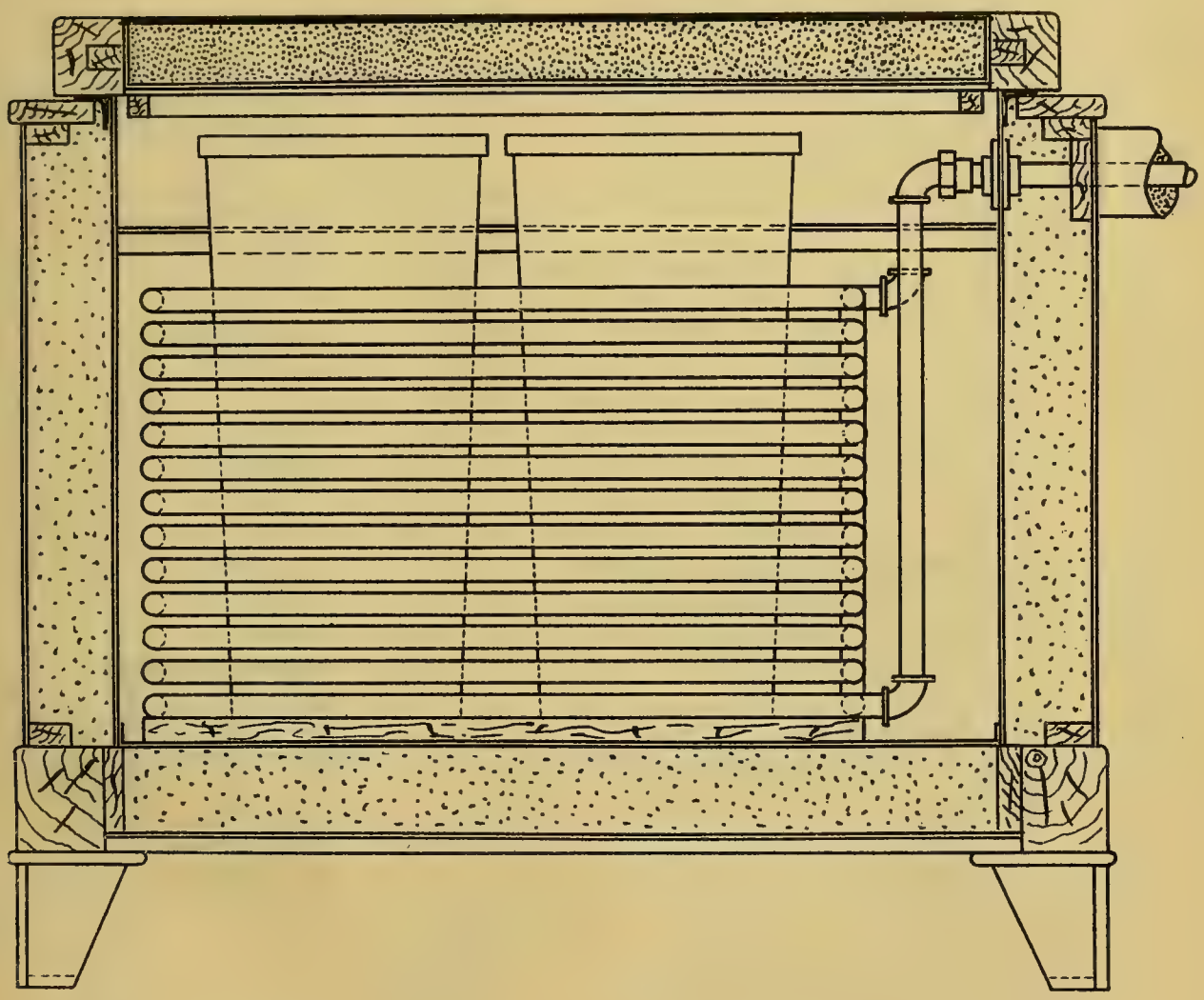
To illustrate paper on "Refrigeration and Refrigerator Insulation on Board Ship," by Robert F. Massa, Esq.



To illustrate paper on "Refrigeration and Refrigerator Insulation on Board Ship," by Robert F. Massa, Esq.



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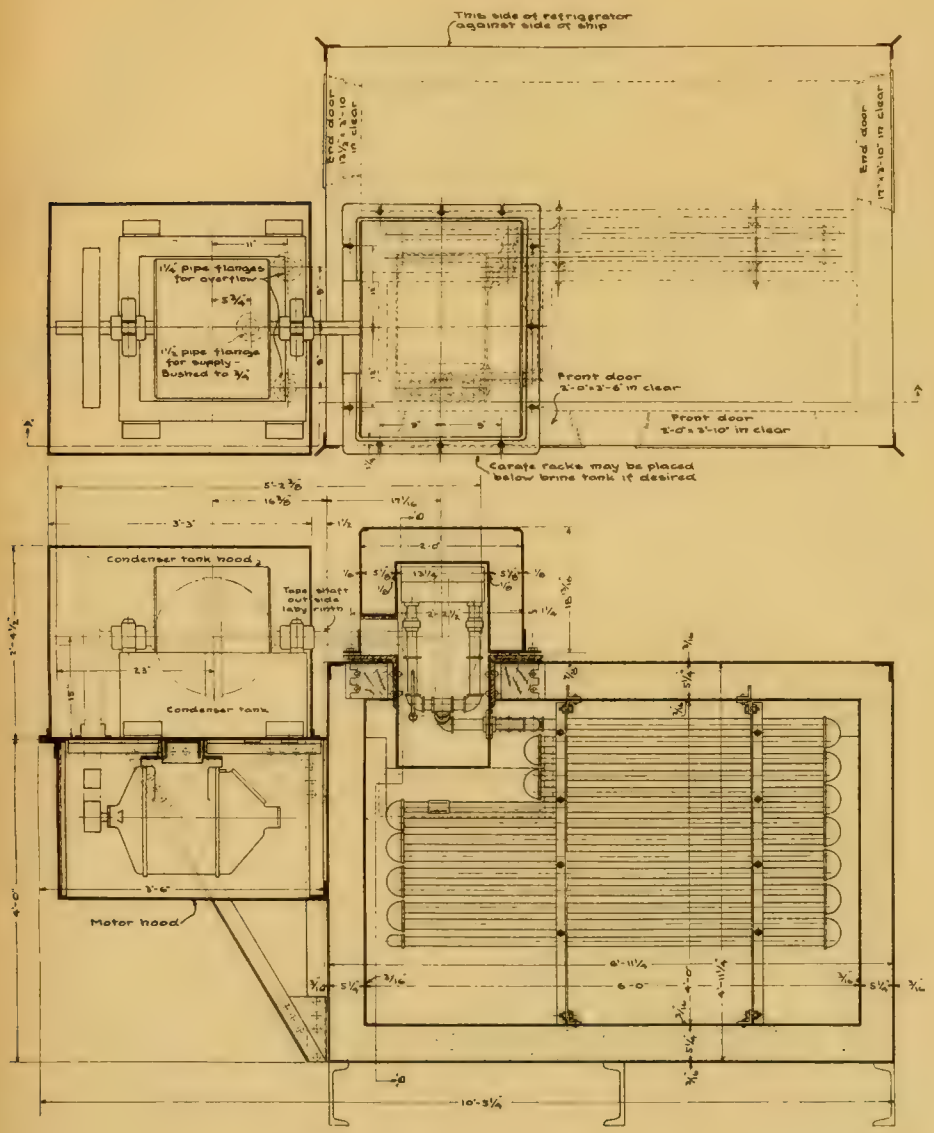
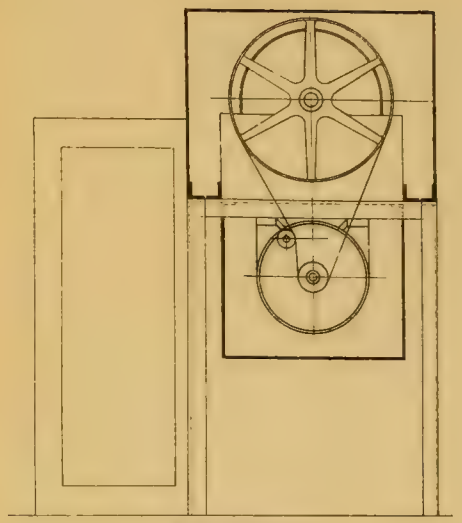
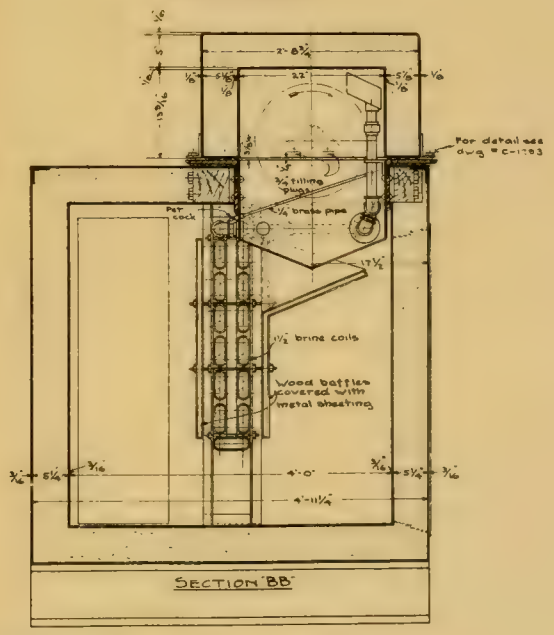
To illustrate paper on "Refrigeration and Refrigerator Insulation on Board Ship," by Robert F. Massa, Esq.



LONGITUDINAL SECTION 'AA'



END ELEVATION



SECTION 'BB'

Motor to be General Electric Co, C.V.C., 112, 1½ H.P., 1150 R.P.M. 120 volt, enclosed motor with three point starter as per Navy Specifications No 17-A-3b.

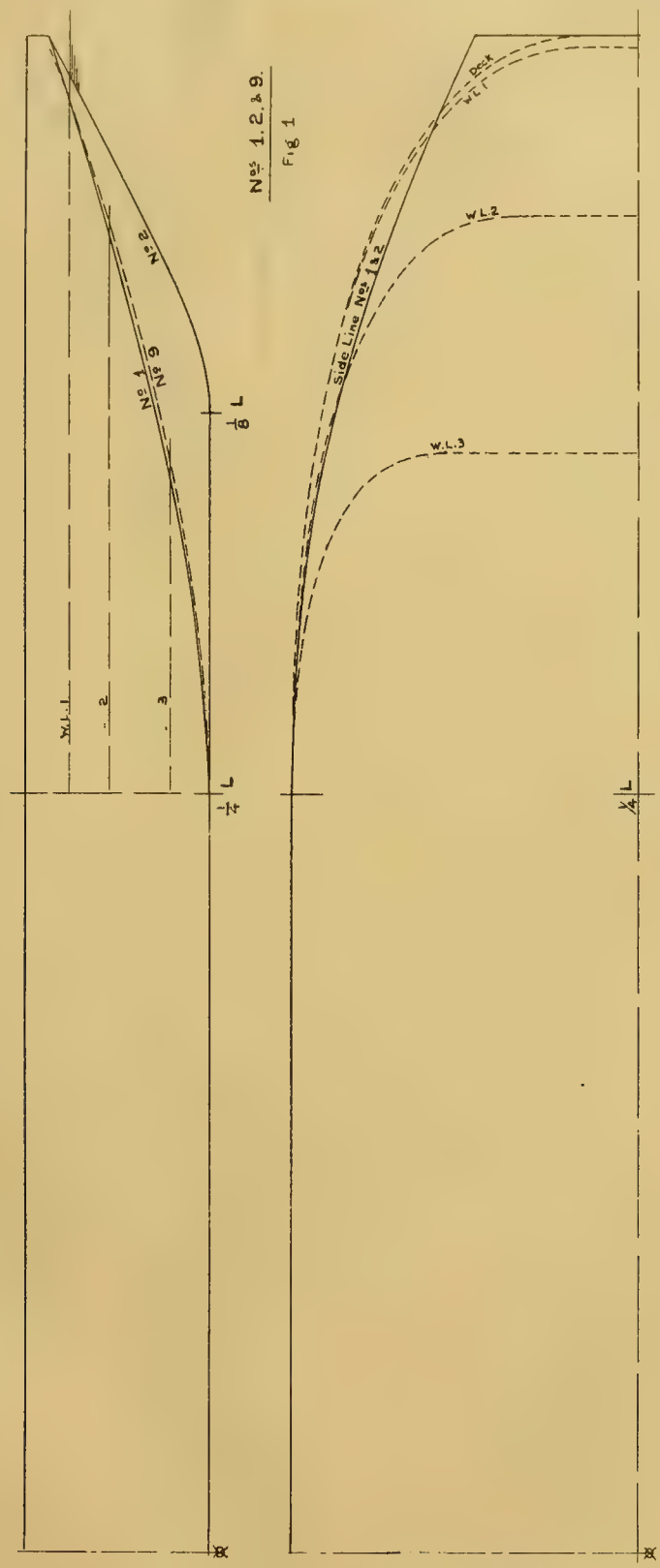
FOR BOATS WHERE REFRIGERATING UNIT SETS AGAINST RAIL

Capacity of No 3 A-S Refrigerating Machine is approximately ½ ton of refrigeration per 24 hours with condensing water overflow temperature of 77° F. and brine temperature of 27° F.

Changed Oct. 14, 1916. - H.P.M.

THE NORRIS PETERS CO., WASHINGTON, D. C.

To illustrate paper on "The Resistance of Various Types of Barges in Shallow and Deep Water," by Professor Herbert C. Sadler, Member of Council.



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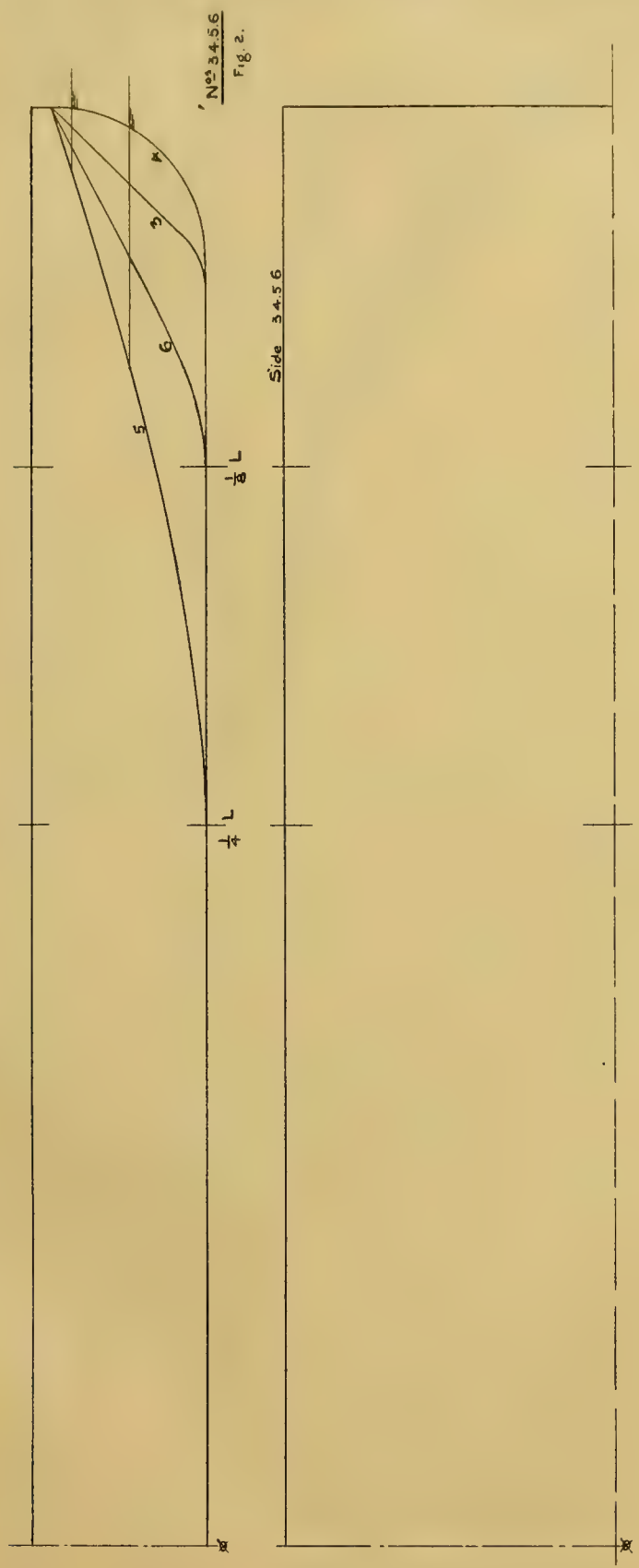

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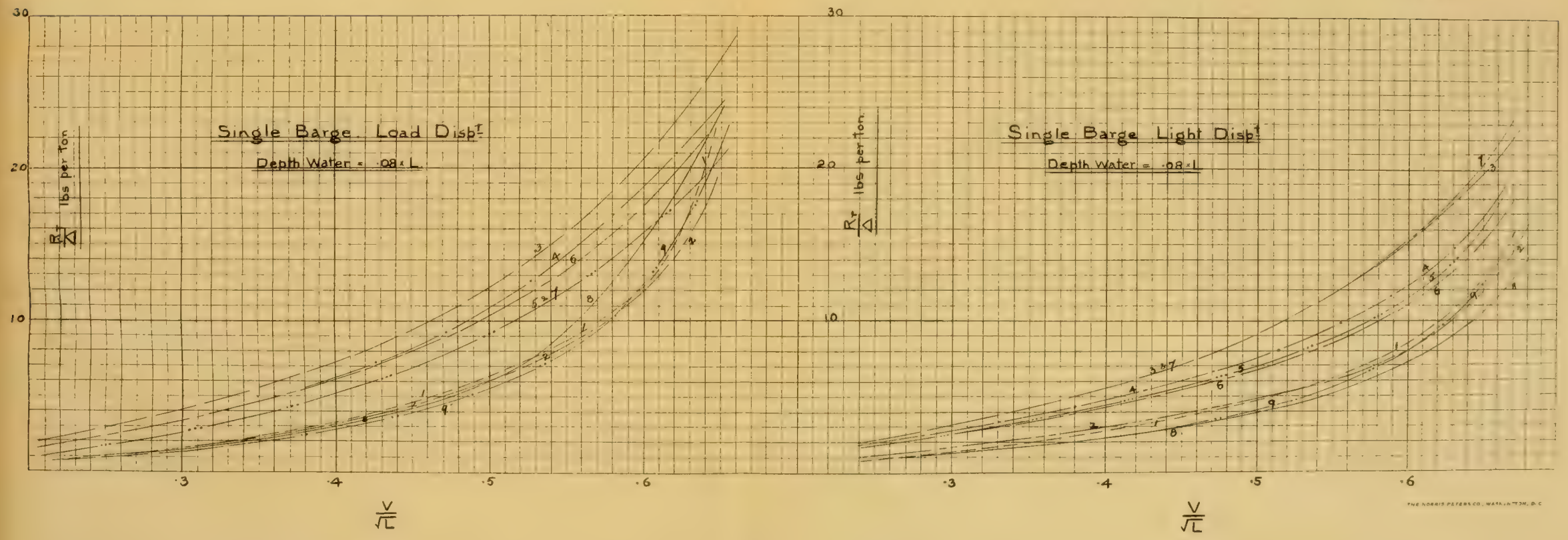
To illustrate paper on "The Resistance of Various Types of Barges in Shallow and Deep Water," by Professor Herbert C. Sadler, Member of Council.

Fig. 4.



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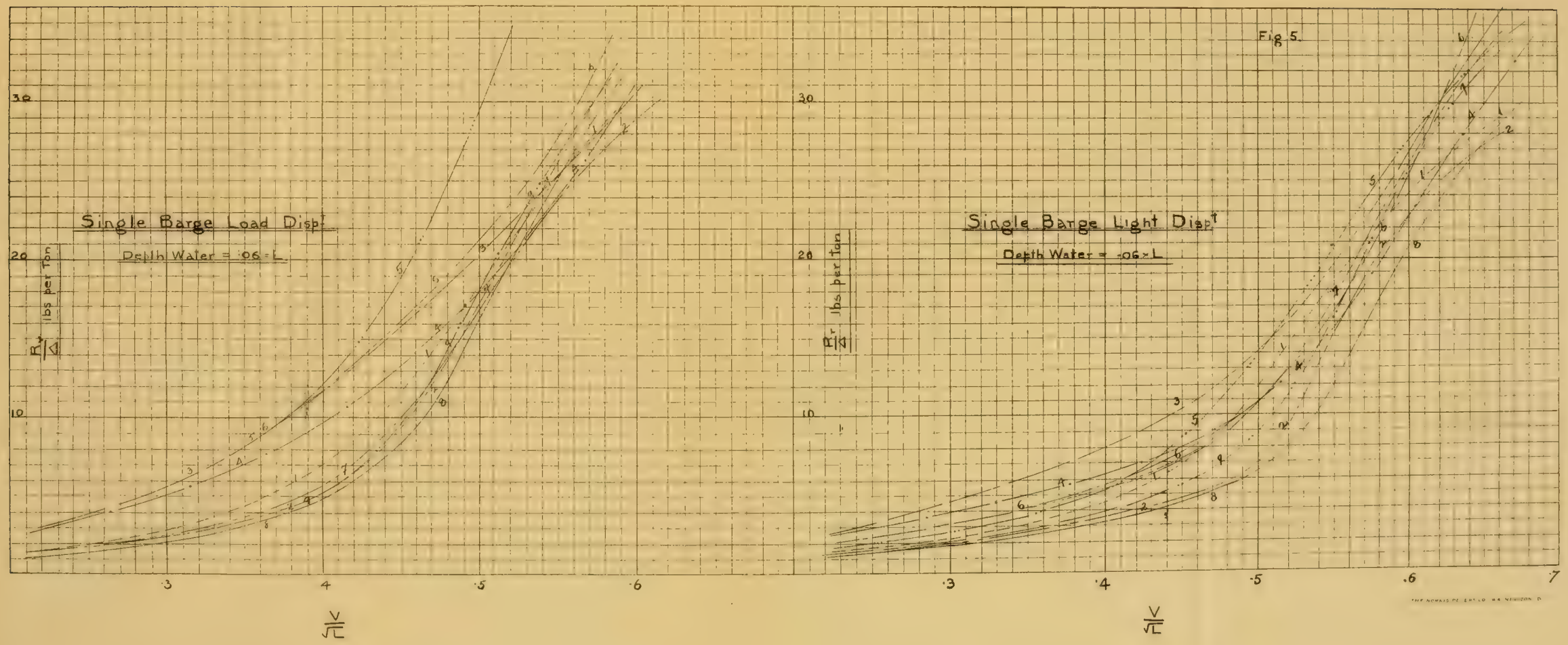

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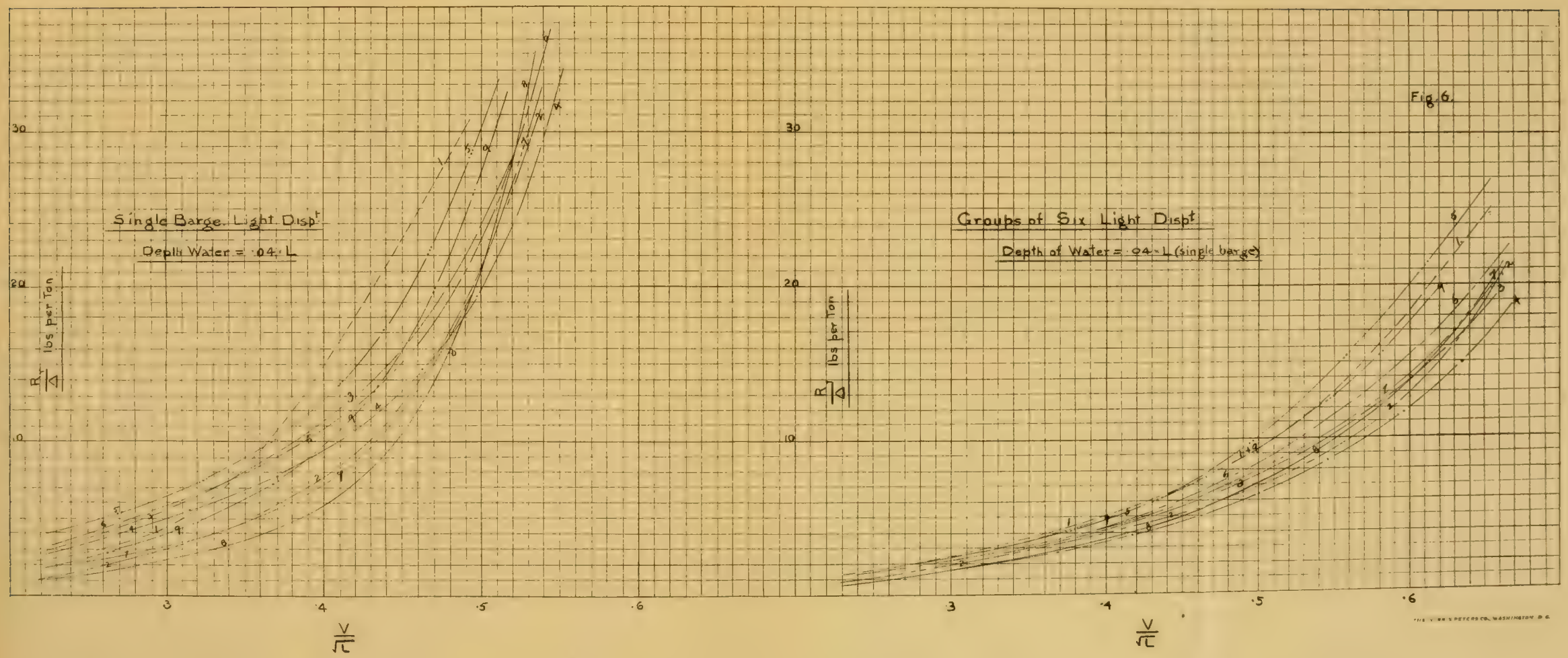

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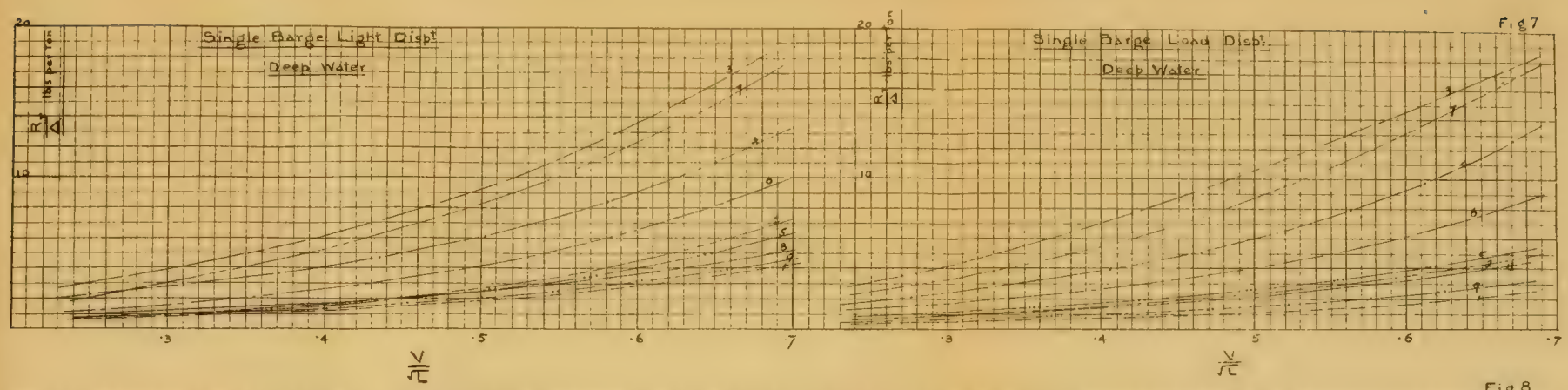

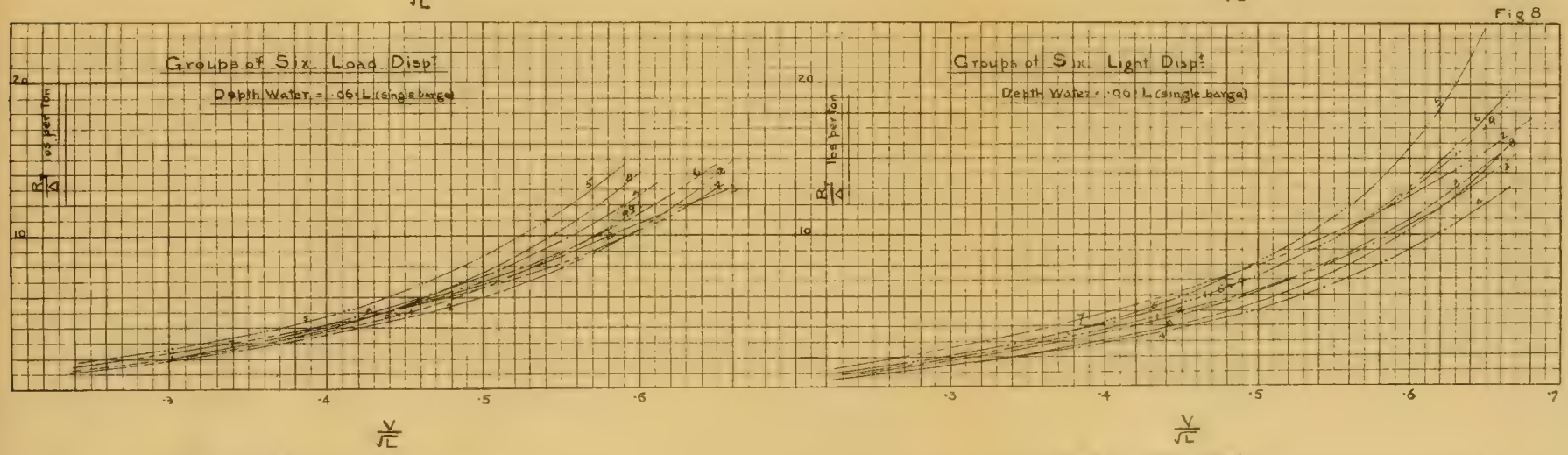

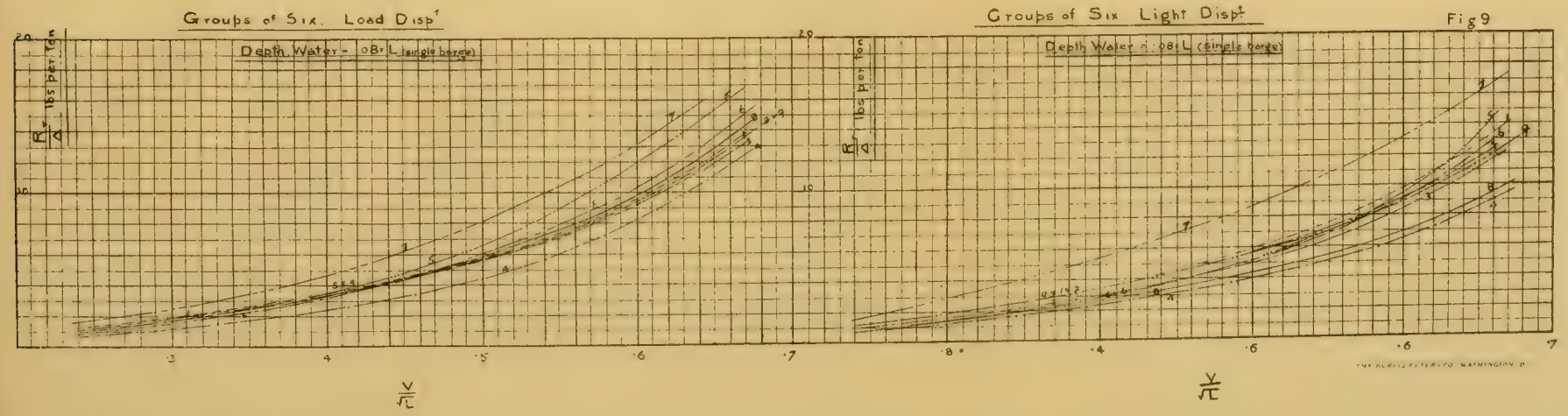

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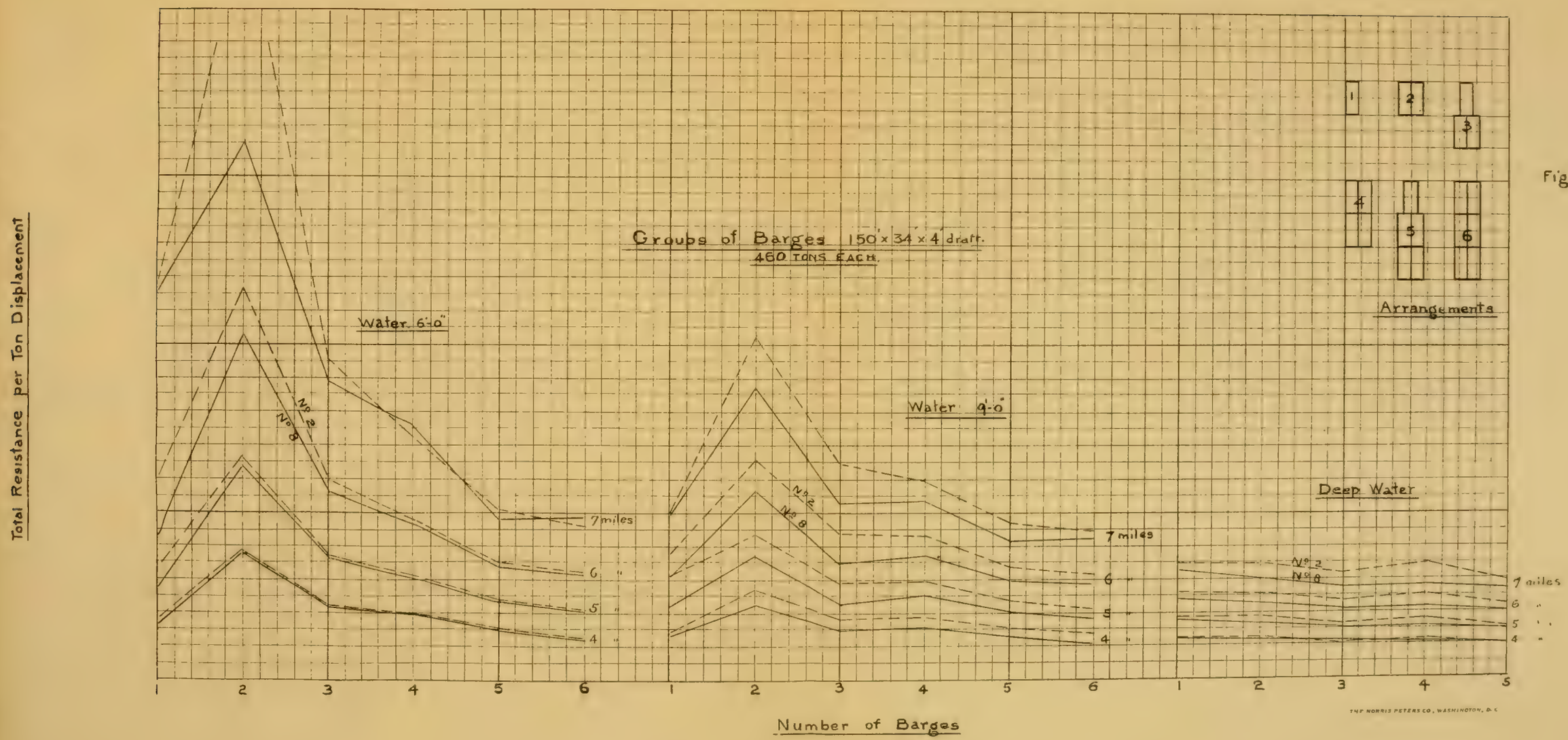


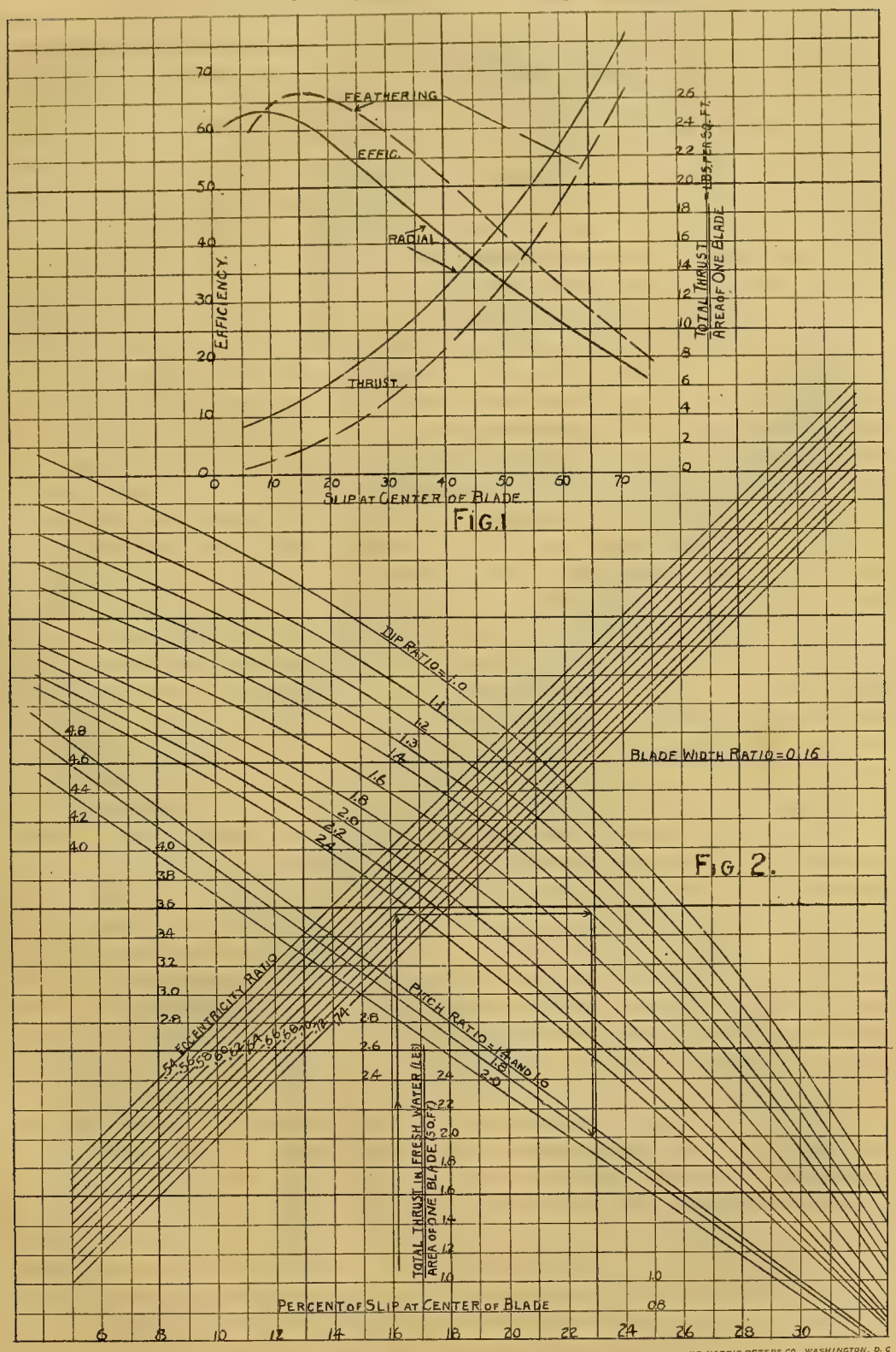
Fig 10.

To illustrate paper on "Feathering Paddle-Wheels," by Professor E. M. Bragg, Member.

Table I.

No.		New York 1 N	New York 1 S	New York 2 N	New York 2 S	New York 3 N	New York 3 S	New York 4 N	New York 4 S	City of Cleveland	Tashmoo	City of Erie	Western States	Detroit III	Commonwealth 1	Commonwealth 2	Commonwealth 3	Commonwealth 4	Henrick Hudson	See-and-bee
1	Length between perpendiculars, feet . . . . . (L')	330.3	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	390	300	314	350	455	438	. . . .	. . . .	. . . .	379	435
2	Distance from bow to wheel, feet . . . . . (S)	216.3	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	221.3	176	202	193.5	232.5	268	. . . .	. . . .	. . . .	159	265
3	$S \div L'$	.655	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	.567	.586	.643	.552	.511	.611	. . . .	. . . .	. . . .	.418	.546
4	Diameter of wheel over blades, feet . . . . . (D)	29.83	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	29.03	22.43	28.5	25.0	29.42	31.0	. . . .	. . . .	. . . .	24.0	30.5
5	Diameter of wheel at trunnions, feet	27.0	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	24.55	19.09	25.16	21.56	24.5	26.75	. . . .	. . . .	. . . .	20.79	25.5
6	Number of blades	12	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	11	9	11	10	11	12	. . . .	. . . .	. . . .	9	11
7	Width of blades, feet . . . . . (W)	3.33	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	4.5	3.75	4.0	4.0	5.0	5.0	. . . .	. . . .	. . . .	4.0	5.0
8	Length of blades, feet	12.5	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	14.0	12.0	12.0	13.0	14.5	14.5	. . . .	. . . .	. . . .	14.5	14.83
9	Area of one blade, square feet . . . . . (A)	41.7	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	63.0	45.0	48.0	52.0	72.5	72.5	. . . .	. . . .	. . . .	58.0	74.2
10	Apparent dip of blades, feet	4.42	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	6.5	4.75	5.16	5.17	6.5	7.58	. . . .	. . . .	. . . .	5.5	. . . .
11	Blade width $\div D$	.112	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	.155	.168	.14	.16	.17	.162	. . . .	. . . .	. . . .	.166	.164
12	Apparent dip $\div D$	.148	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	.223	.211	.181	.20	.22	.244	. . . .	. . . .	. . . .	229	. .
13	Apparent dip ratio = dip $\div W$	1.32	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	1.44	1.27	1.29	1.29	1.30	1.52	. . . .	. . . .	. . . .	1.38	. . . .
14	Pitch ratio	2.13	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	1.56	1.78	1.8	1.7	1.4	1.4	. . . .	. . . .	. . . .	1.81	1.46
15	Eccentricity, inches . . . . . (E)	13.5	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	22.0	17.5	22.3	23.0	26.5	29.0	. . . .	. . . .	. . . .	22.5	28.0
16	Length of rocker arm, inches . . . . . (L)	24.0	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	36.0	30.0	34.0	36.0	42.0	42.0	. . . .	. . . .	. . . .	36.0	42.0
17	$E \div L$	.562	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	.61	.584	.654	.64	.63	.69	. . . .	. . . .	. . . .	.624	.667
18	Speed of boat, knots . . . . . (V)	11.1	10.73	14.55	13.8	17.9	17.7	18.87	18.64	17.4	18.9	18.9	16.7	18.3	20.0	18.9	16.7	13.8	20.0	. . . .
19	Speed-length ratio	.612	.591	.802	.76	.986	.975	1.04	1.03	.88	1.09	1.07	.89	.89	.957	.903	.795	.66	1.03	. . . .
20	Speed of advance, feet per minute . . . . . (v)	1122	1089	1473	1400	1811	1795	1910	1888	1760	1910	1913	1690	1850	2030	1916	1686	1397	2026	. . . .
21	Apparent slip at center of blade, per cent	15.0	15.0	15.0	15.0	15.9	15.5	19.6	17.9	17.2	18.6	25.4	17.0	14.6	16.7	14.9	15.0	15.5	22.3	. . . .
22	R. P. M.	15.9	15.4	20.8	19.8	25.8	25.5	28.2	27.6	27.6	40.0	33.3	30.9	28.3	29.8	27.5	24.3	20.3	41.5	. .
23	I. H. P.	540	529	1035	973	2310	2297	3132	2843	6420	3400	6472	3864	7606	12000	8625	5350	3020	5500	. . . .
24	Length of wave $= 0.5573V^2$, feet	68.4	64.3	118	106	178	175	198	194	169	199	199	156	185	222	199	156	106	222	. . . .
25	Wave crest aft of bow, feet	8.2	7.7	14.0	13.0	21.0	21.0	24.0	23.0	20.0	24.0	24.0	19.0	22.0	27.0	24.0	19.0	13.0	27.0	. . . .
26	Distance from bow wave to wheel, feet	208.1	208.6	202.3	203.3	195.3	195.3	192.3	193.3	201.3	152	178	174.5	210.5	241	244	249	255	132	. . .
27	(26) : (24)	3.04	3.24	1.72	1.92	1.1	1.11	.97	.995	1.19	.763	.893	1.12	1.14	1.10	1.23	1.60	2.41	594	. .
28	$v \div 100 \sqrt{D}$	2.05	1.99	2.69	2.56	3.31	3.29	3.5	3.45	3.26	4.01	3.57	3.37	3.43	3.65	3.44	3.03	2.51	4.13	. . . .
29	Displacement of boat at trial, long tons	1240	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	4510	1170	2233	2692	5687	5430	. . . .	. . . .	. . . .	1972	. . . .
30	Displacement-length coefficient $\div 100$	.343	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	.763	.432	.72	.627	.605	.643	. . . .	. . . .	. . . .	.36	. . .
31	$\sqrt[5]{(19) \times (30)}$	.732	.727	.773	.764	.805	.803	.814	.812	.923	.860	.949	.890	.884	.912	.897	.875	.843	.823	. . . .
32	Wheel efficiency at apparent slip and apparent dip . . (e)	.68	.68	.68	.68	.675	.675	.655	.665	.63	.65	.61	.655	.63	.62	.615	.615	.62	.625	. . . .
33	(I. H. P. $\times$ 33,000 $\times$ .85 $\times$ e) $\div 2Av = T'$ (salt water)	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	707	536	378	260	. . . .	. . . .
34	(I. H. P. $\times$ 33,000 $\times$ .85 $\times$ e) $\div 2Av = T$ (fresh water)	111	111	161	159	289	291	362	338	514	361	604	405	502	690	522	369	254	411	. . . .
35	$(v \div 100)^2$	126	119	217	196	328	322	365	356	310	365	366	286	342	412	367	284	195	411	. . . .
36	$T \div (v \div 100)^2 = t$; pounds per square foot	.88	.93	.74	.81	.88	.90	.99	.95	1.66	.99	1.65	1.42	1.47	1.67	1.42	1.30	1.30*	1.00	. . .
37	Slip for t at .125 blade width ratio, per cent	9.7	10.2	8.3	9.0	9.7	9.9	10.7	10.3	14.7	10.3	16.1	. . . .	14.8	16.1	14.5	13.7	13.7	10.0	. . . .
38	Slip for t at .16 blade width ratio, per cent	7.2	7.8	5.8	6.5	7.2	7.5	8.3	7.9	12.0	7.7	14.5	12.1	12.1	13.2	11.3	10.4	10.4	7.6	. . . .
39	Slip for t at wheel's blade width ratio, per cent	10.6	11.1	9.2	9.9	10.6	10.8	11.6	11.2	12.3	7.1	15.4	12.1	11.3	13.0	11.1	10.2	10.2	7.2	
40	Virtual slip (39) $\div$ apparent slip (21)	.71	.74	.61	.66	.67	.70	.59	.63	.72	.38	.61	.71	.77	.78	.75	.68	.66	.32	. .
41	(40)$\div$(31)	.97	1.02	.79	.86	.83	.87	.73	.77	.78	.44	.64	.80	.87	.86	.84	.78	.78	.39	. . .
42	$(v \div 100)^{1.76}$	69.2	64.6	110.8	101.3	158.5	154.9	173.7	169.8	151.2	173.7	175.0	141.0	165.0	194.1	175.5	140.3	101.0	193.7	. . .
43	Assumed virtual dip ratio	1.41	1.54	1.3	1.4	1.48	1.6	1.25	1.36	2.18	1.04	1.25	1.82	2.08	2.6	2.4	2.1	1.9	0.9	. . . .
44	Wheel efficiency at apparent slip and virtual dip . . . (e)	.68	.665	.68	.68	.67	.66	.675	.675	.58	.67	.613	.62	.575	.54	.55	.57	.59	.67	. . . .
45	(I. H. P. $\times$ 33,000 $\times$ .85 $\times$ e) $\div 2Av = T$ (fresh water)	111	109	161	159	287	285	372	343	472	372	606	383	458	601	468	342	241	440	.
46	$T \div (v \div 100)^{1.76} = t$ (fresh water)	1.60	1.68	1.45	1.57	1.81	1.84	2.14	2.02	3.12	2.14	3.47	2.72	2.78	3.09	2.66	2.44	2.38	2.26	. . . .
47	Dip ratio for t at .125 blade width ratio	1.34	1.45	1.22	1.32	1.41	1.52	1.21	1.31	2.7	1.13	1.31	. . . .	3.6	. . . .	. . . .	. . . .	. . . .	97	.
48	Dip ratio for t at .16 blade width ratio	1.14	1.21	1.03	1.13	1.22	1.29	1.09	1.16	2.07	1.06	1.17	1.82	2.4	2.6	2.4	2.1	1.9	.9	. . . .
49	Virtual dip ratio	1.41	1.54	1.3	1.4	1.48	1.6	1.25	1.36	2.18	1.04	1.25	1.82	2.08	2.6	2.4	2.1	1.9	.89	. . . .
50	Virtual dip ratio $\div$ apparent dip ratio	1.07	1.17	.98	1.06	1.12	1.21	.95	1.03	1.52	.82	.97	1.45	1.6	1.71	1.58	1.38	1.25	645	. .
51	(50) (31)	1.46	1.61	1.27	1.37	1.37	1.51	1.16	1.27	1.64	.95	1.02	1.63	1.81	1.88	1.76	1.58	1.48	.78	.

To illustrate paper on "Feathering Paddle-Wheels," by Professor E. M. Bragg, Member.



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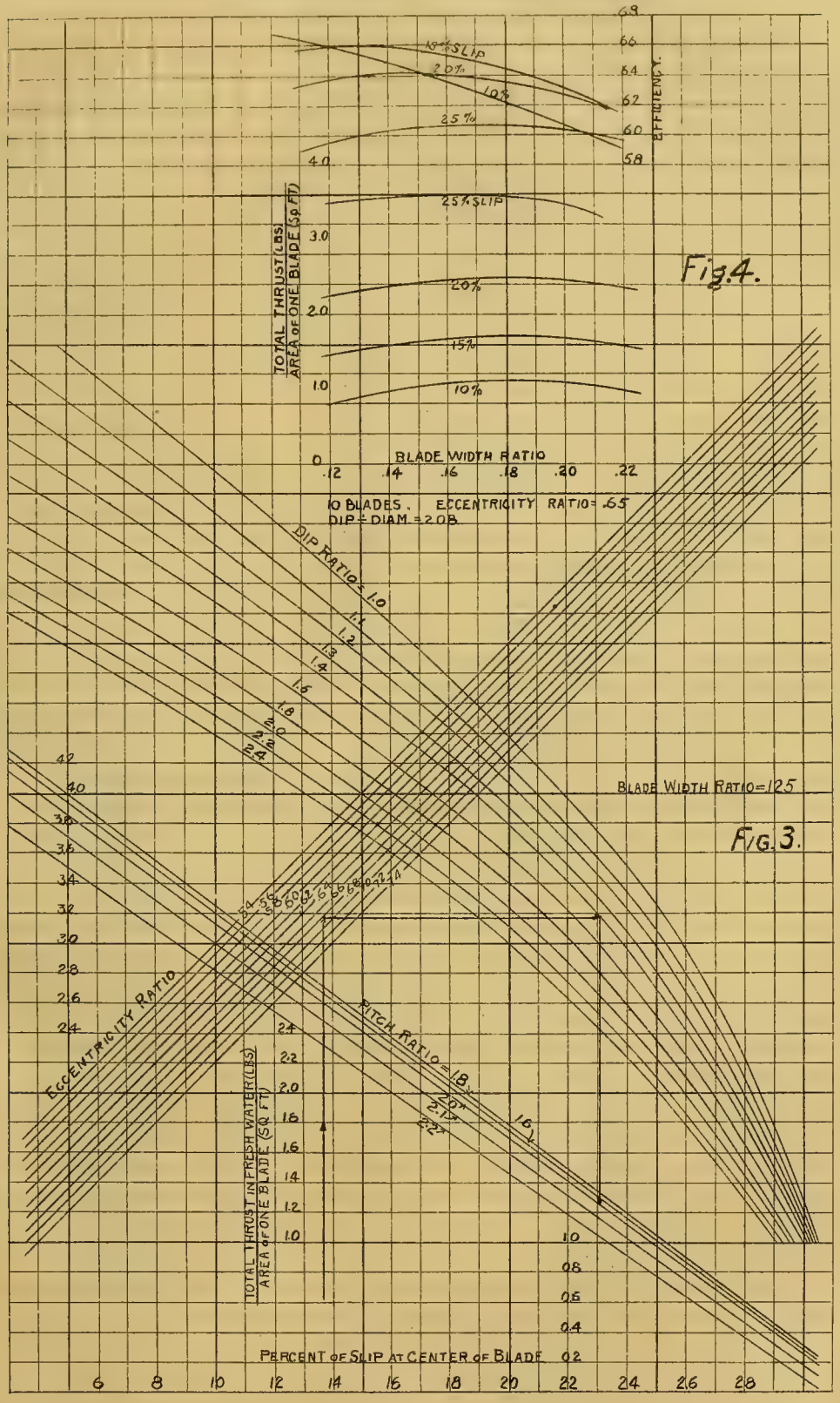
To illustrate paper on "Feathering Paddle-Wheels," by Professor E. M. Bragg, Member.



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To illustrate paper on "Feathering Paddle-Wheels," by Professor E. M. Bragg, Member.

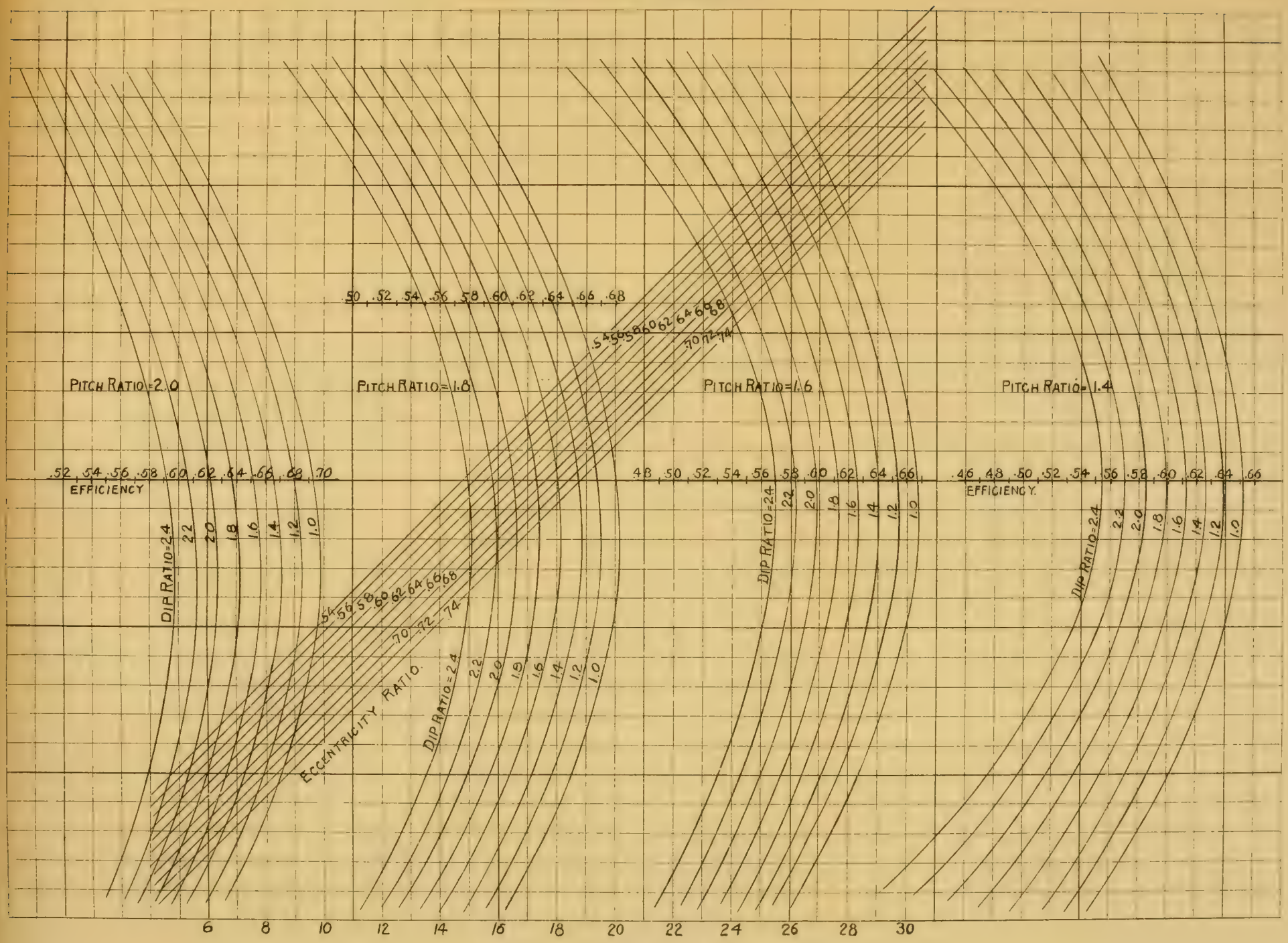

FIG. 5.

To illustrate paper on "Feathering Paddle-Wheels," by Professor E. M. Bragg, Member.

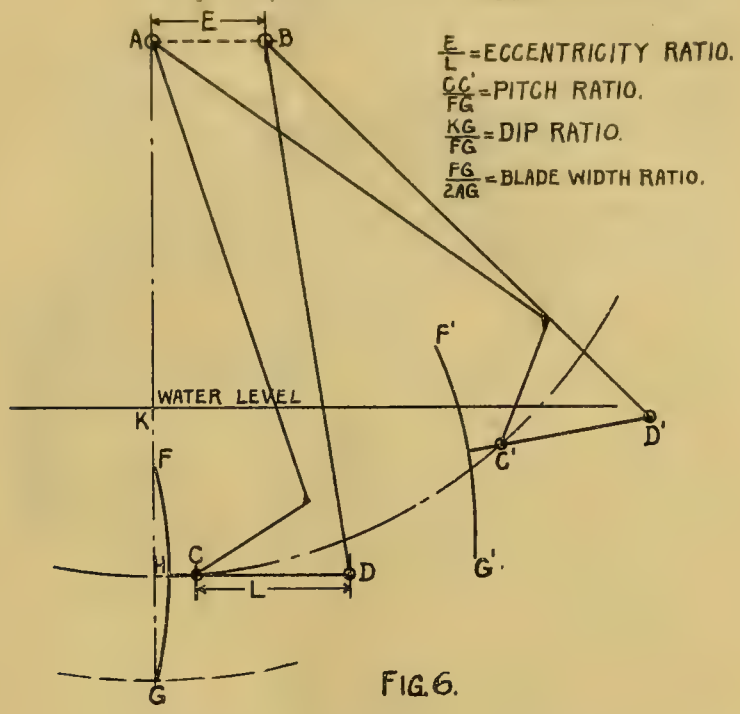

FIG. 6.

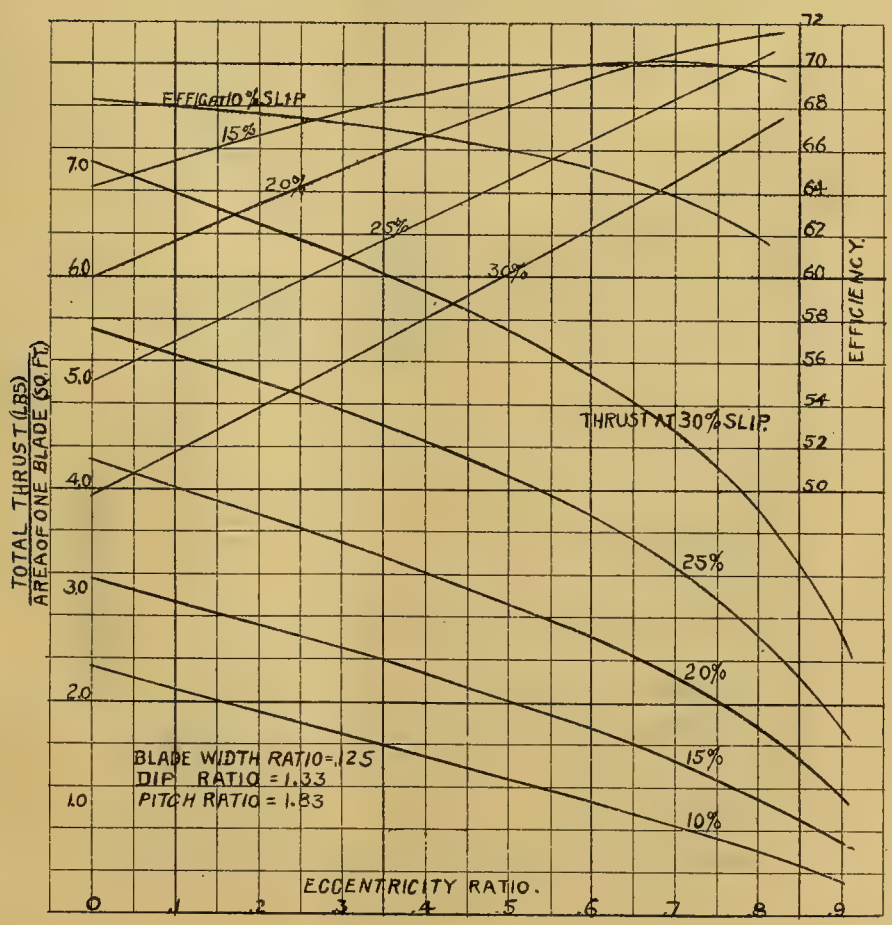

FIG. 7

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To illustrate paper on "Feathering Paddle-Wheels," by Professor E. M. Bragg, Member.

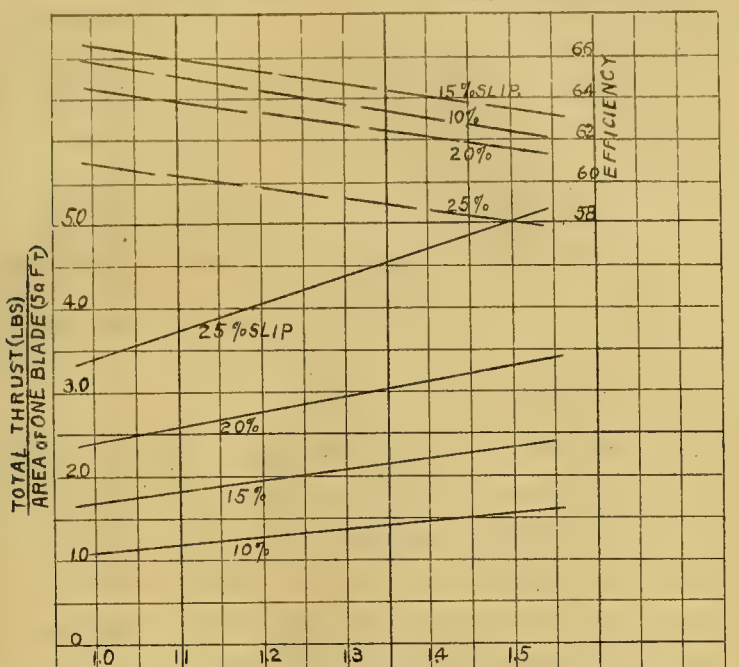
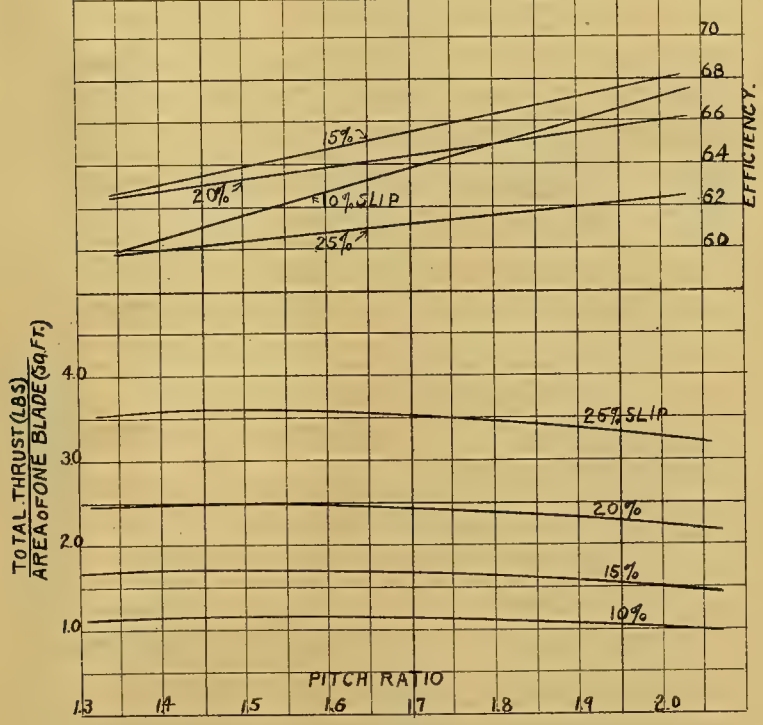


FIG. 8.



BLADE WIDTH RATIO = .16 DIP RATIO = 1.25 ECC. RATIO = .66

FIG. 9.

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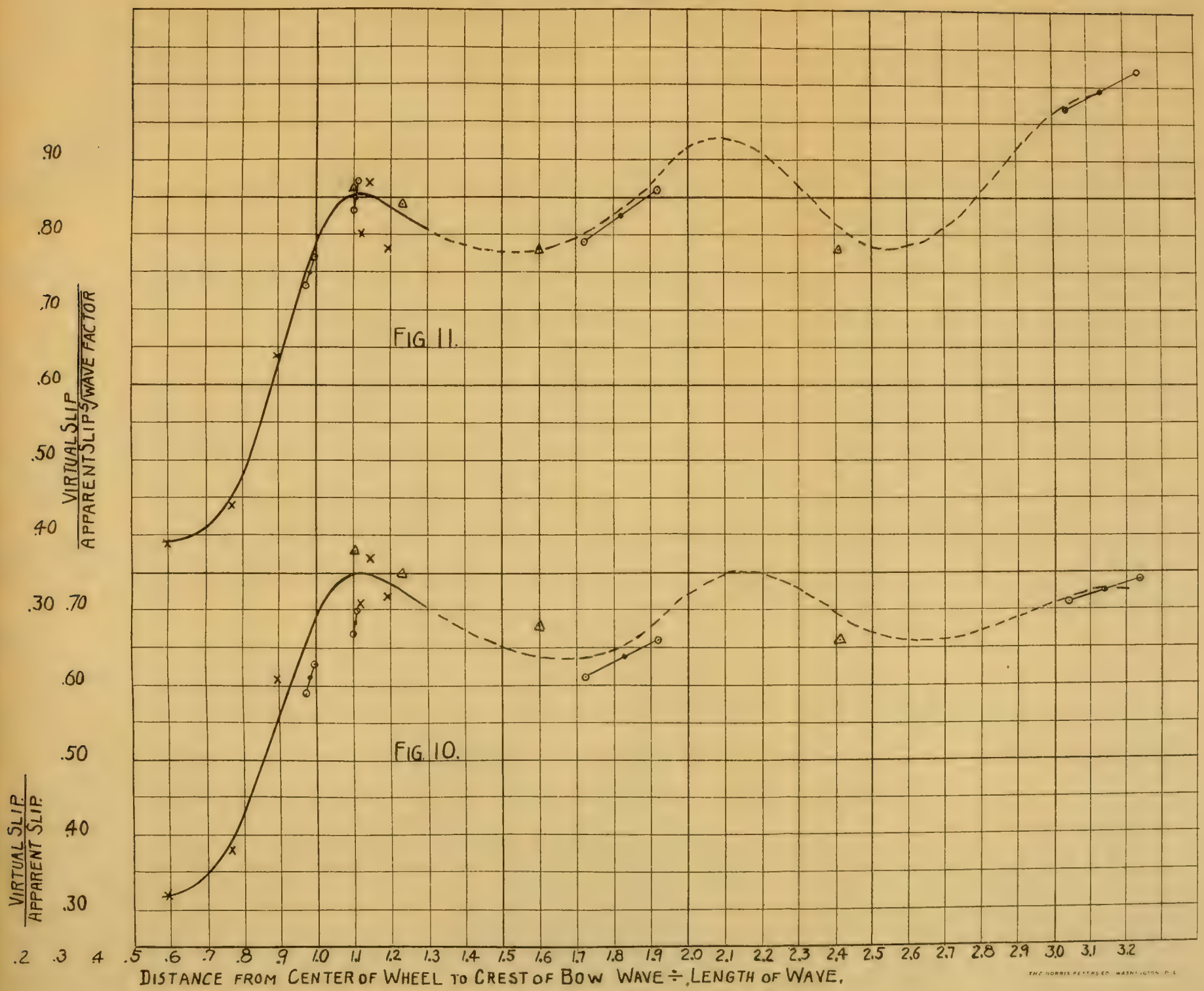
To illustrate paper on "Feathering Paddle-Wheels," by Professor E. M. Bragg, Member.



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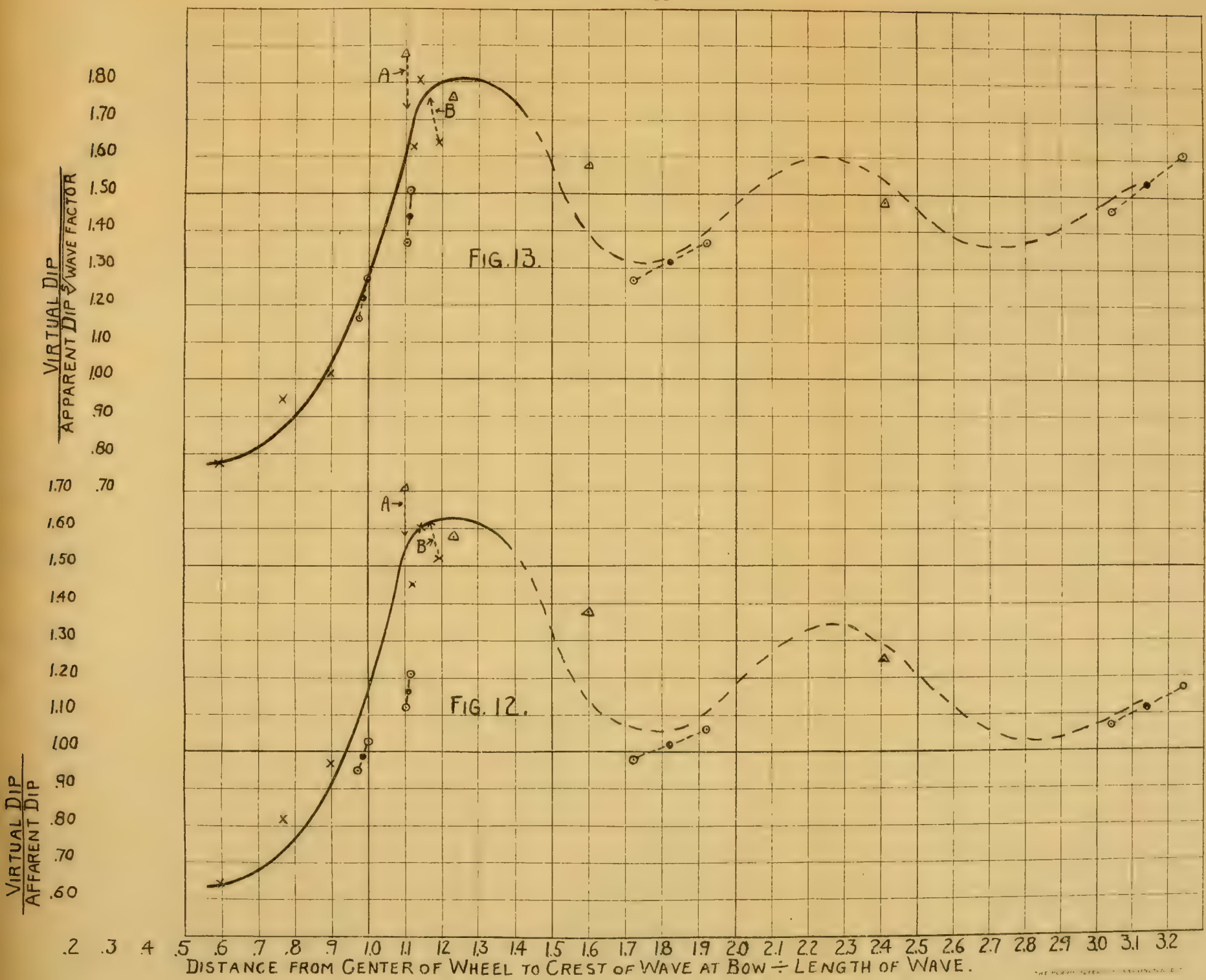


To illustrate paper on "Feathering Paddle-Wheels," by Professor E. M. Bragg, Member.

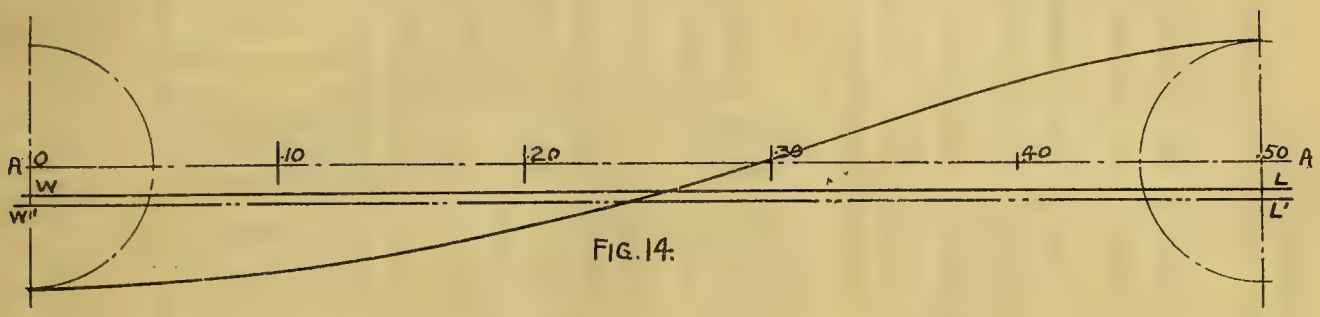


FIG. 14.

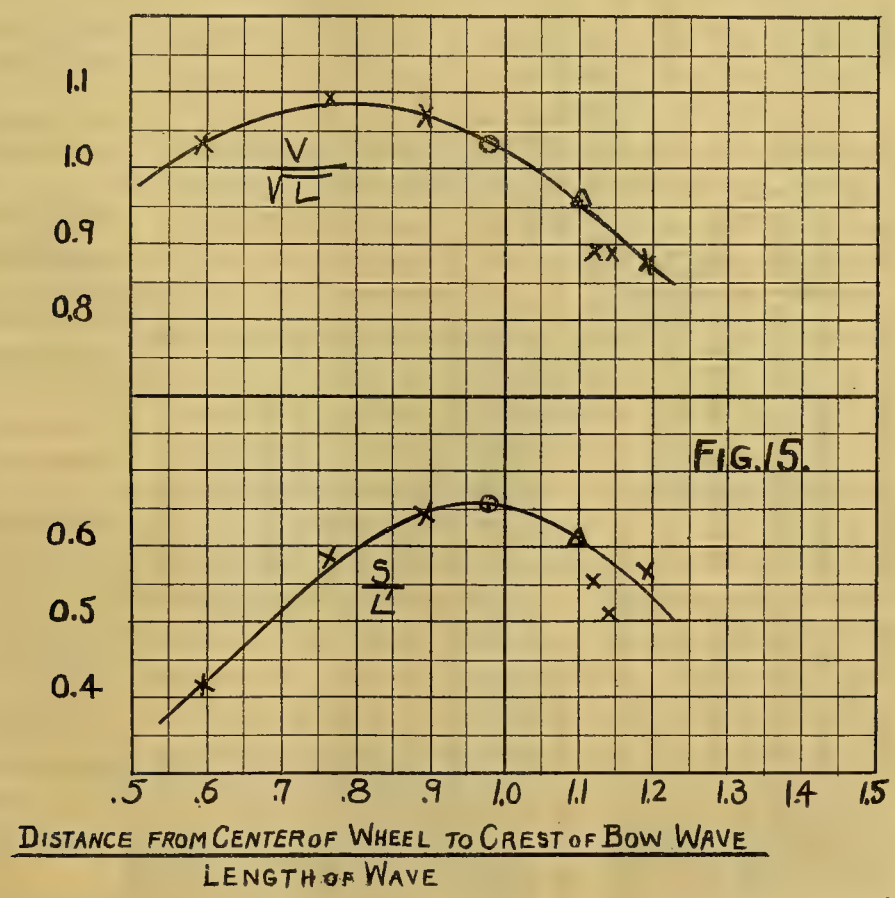


FIG. 15.

THE NORRIS-PETERS CO., WASHINGTON, D. C

To illustrate paper on "Alquist Gearing for Ship Propulsion," by W. L. R. Emmet, Esq., Member of Council.

S. S. "LA BREA."

VOYAGE.	DATE.	TOTAL DISTANCE IN KNOTS.	AVERAGE SPEED IN KNOTS PER HOUR.	TOTAL BARRELS DELIVERED.	NAME OF PORT	TOTAL FUEL USED STEAMING ON VOYAGE IN BARRELS	TOTAL BARRELS PER KNOTS STEAMING.	TOTAL BARRELS USED IN PORT	TOTAL BARRELS PER KNOT STEAMING AND IN PORT.	TIME IN PORT HOURS.	BARRELS DISCHARGED PER HOUR.	COST AT 80¢ PER BBL. PER KNOT STEAMING AND IN PORT (FUEL)	SHAFT HORSE POWER HOURS.	POUNDS OF OIL PER SHAFT HORSE POWER HOUR.	
1	MAR. 9 TO 15 1916	650	9.5	62578	OLEUM	574	.883	142	1.10	36½	1714	.88	116000	1.67	
2	MAR. 15 TO 26	2037	11.33	73600	SEATTLE	1459	.716	152	.79	37½	1962	.632	505000	.941	
3	MAR 28 TO APR. 6	2108	11.01	64676 8642	VANCOUVER SEATTLE	1584	.751	155	.824	26 13½	2487 640	.659	530000	1.01	
4	APR. 8 MAY 16	92545	10.97	52109 19045	TALTAL ANTO-PAGASTA	6896	.745	117	757	33¾ 15½	1544 1228	.605	2330000	1.00	
5	MAY 17 TO 23	450	11.20	77292	OLEUM	321	.713	134	1.01	39	1980	.808	118000	.911	
6	MAY 24 TO JULY 1ST	9196.5	10.65	71824	ANTO-PAGASTA	6900	.75	109	.762	25	2660	.609	2200000	1.06	
7	JULY 1ST TO AUG 9TH 16	9184	10.39	71791	PORT SAN LUIS TO ANTO PAGASTA CHILE & RETURN	6875	.748	107	.76	42.3	1697	.609	2230000	1.04	

TOTAL POUNDS OF OIL STEAMING = 8270000 TOTAL SHAFT HORSE POWER HOURS 8029000
AVERAGE SPEED. 10.7 POUNDS OF OIL PER SHAFT HORSE POWER HOUR = 1.03

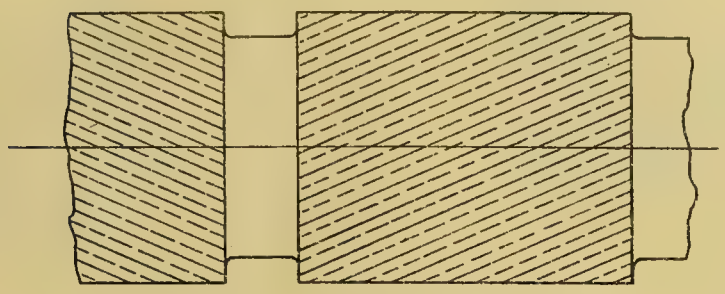
S. S. "LOS ANGELES"

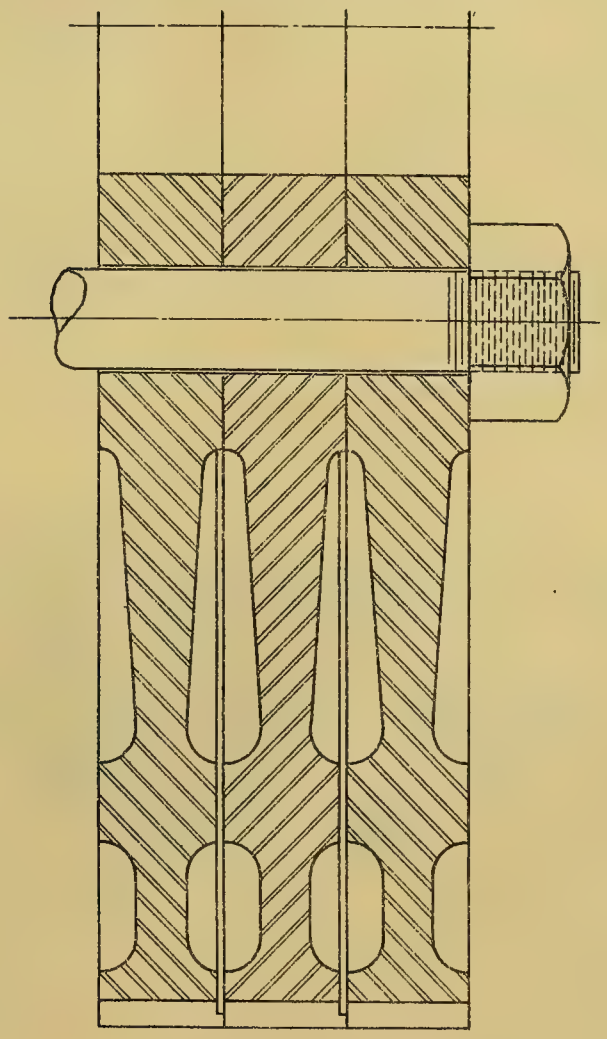
1	APR. 9 TO 15TH	423	9.4	67674	OLEUM	556	1.31	164	1.70	64½	1099	$1.36	74600	2.48	
2	APR. 16 TO 26	1845	10.13	74739	VANCOUVER	1656	.897	218	1.01	33¾	2214	.808	399000	1.41	
3	APR. 27 TO MAY 25	6549	10.22	73734	PANAMA	5579	.851	169	.877	46¾	1577	.701	1420000	1.315	
4	MAY 26 TO 29	220	9.1	72372	OLEUM	221	1.00	123	1.56	41	1770	1.24	39000	1.88	
5	MAY 30 JUNE 27	6348	10.6	72538	BAL-BOA	5462	.86	159	.885	35	2072	.708	1460000	1.255	
6	JUNE 29 AUG. 7-16	9151	10.24	71007	PORT SAN LUIS TO ANTO PAGASTA CHILE & RETURN	8293	.906	186	.926	56.3	1261	.74	2130000	1.31	
AVERAGE SPEED			10.27												

TOTAL POUNDS OF OIL STEAMING = 7310000 TOTAL SHAFT HORSE POWER HOURS 5538000
POUNDS OF OIL PER SHAFT HORSE POWER HOUR = 1.320

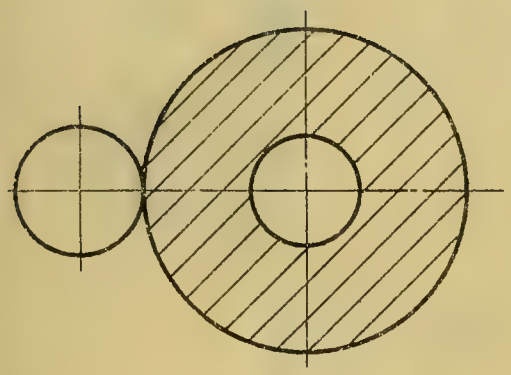
THE HORRIS PETERS CO., WASHINGTON, D. C.

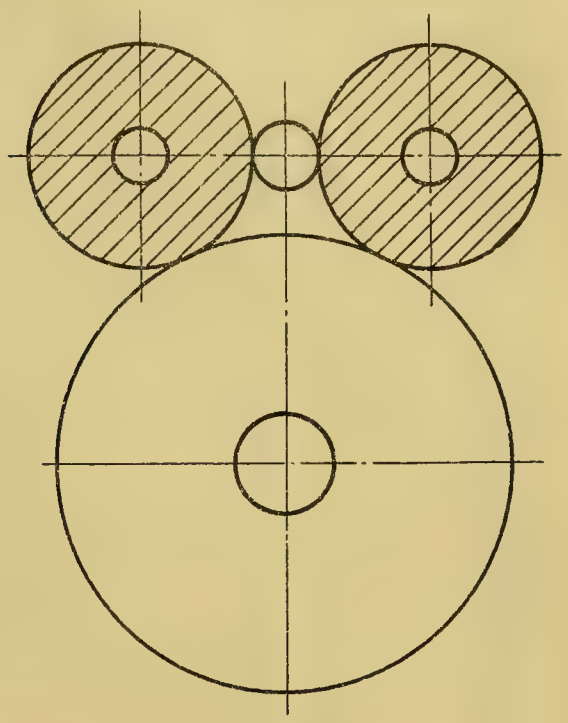
To illustrate paper on "Alquist Gearing for Ship Propulsion," by W. L. R. Emmet, Esq., Member of Council.

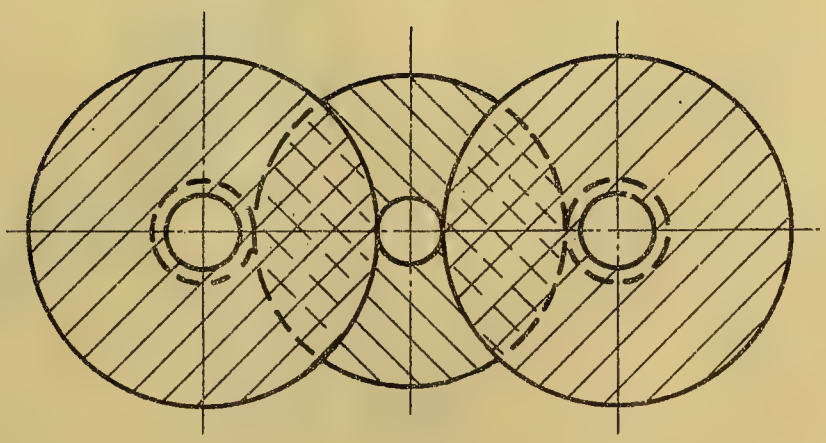




To illustrate paper on "Alquist Gearing for Ship Propulsion," by W. L. R. Emmet, Esq., Member of Council.







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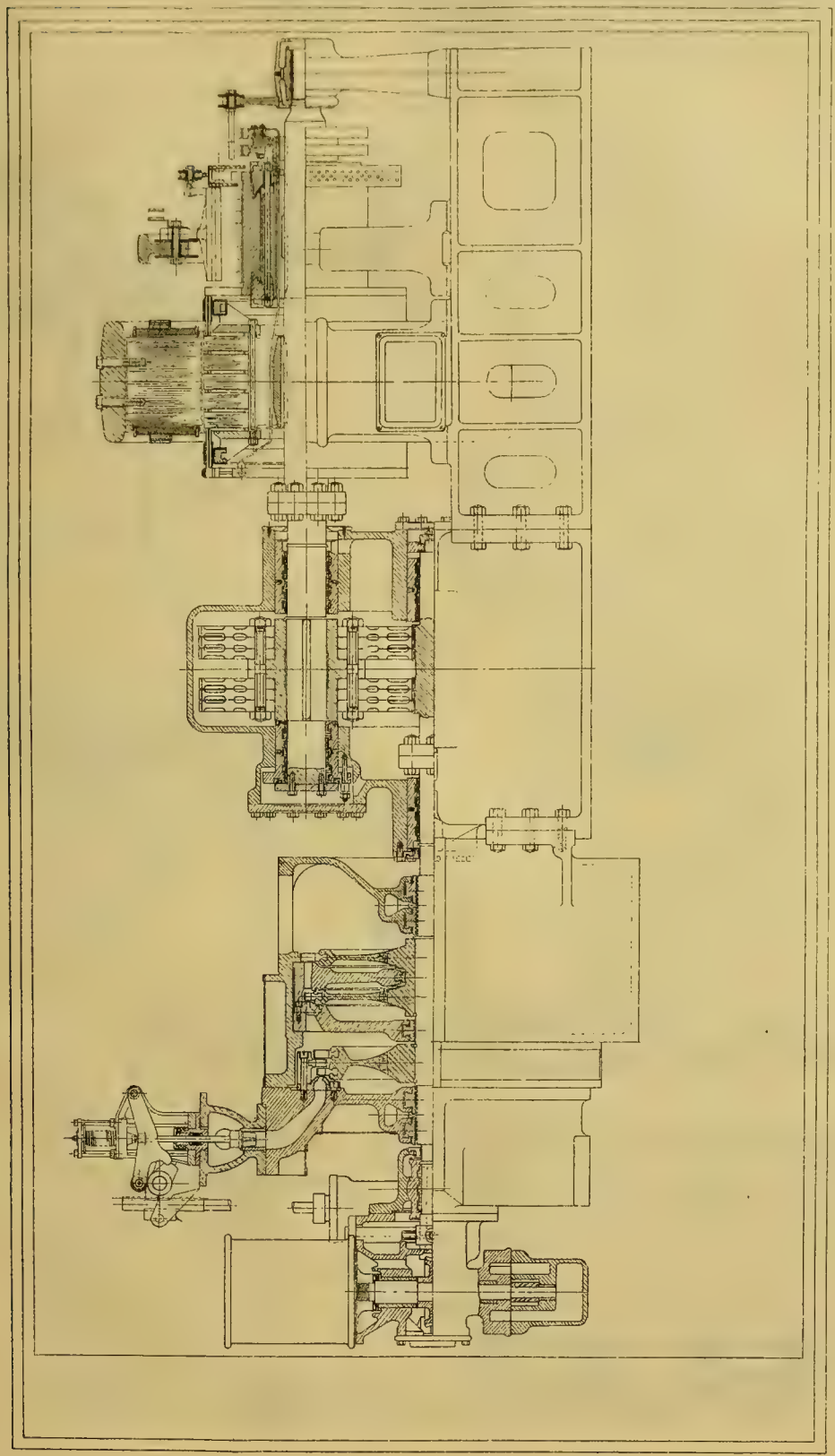
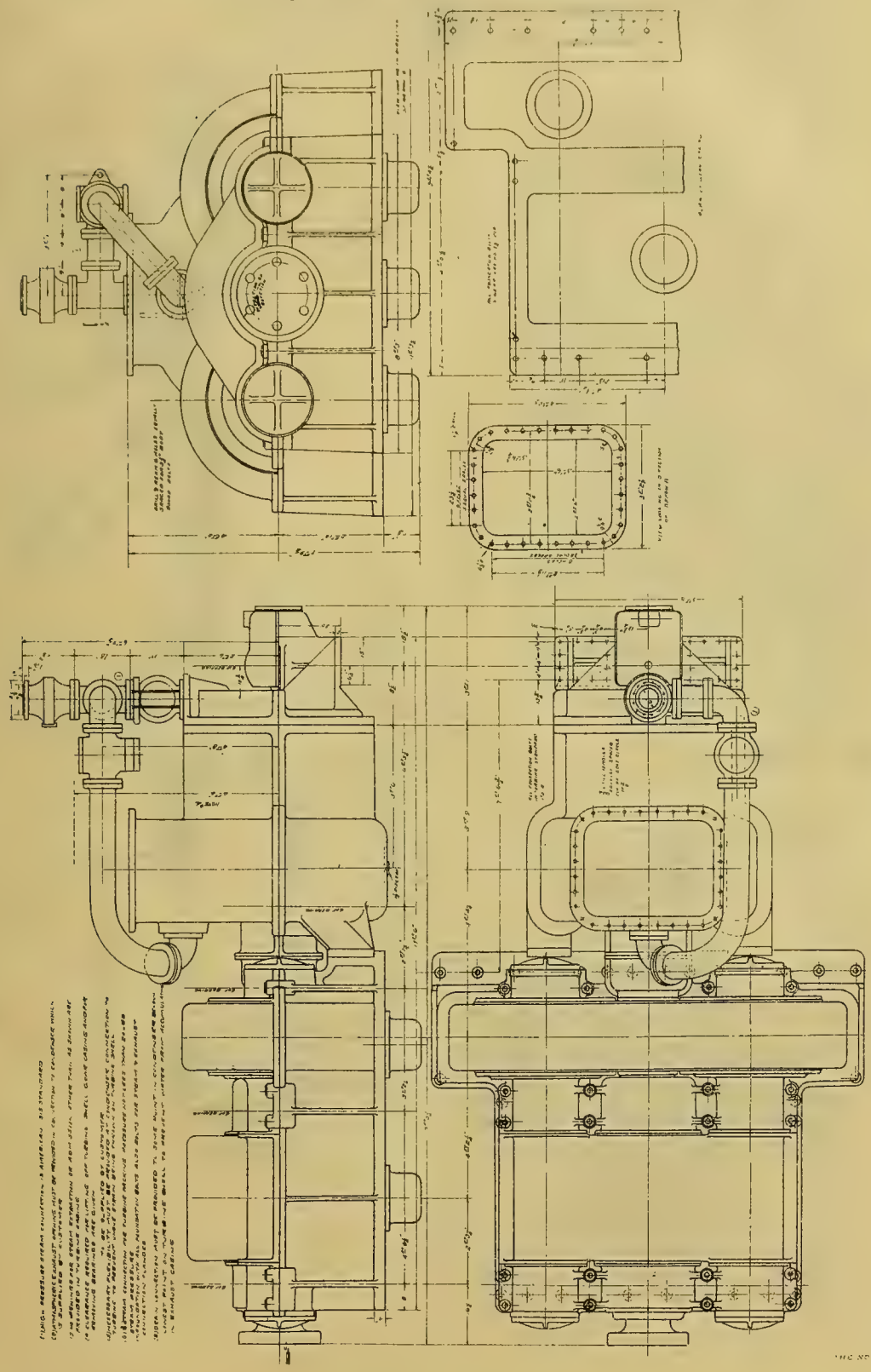


ASSEMBLY - 300 KW TURBINE GEARED TO DIRECT CURRENT GENERATOR - 5000/1000 RPM.

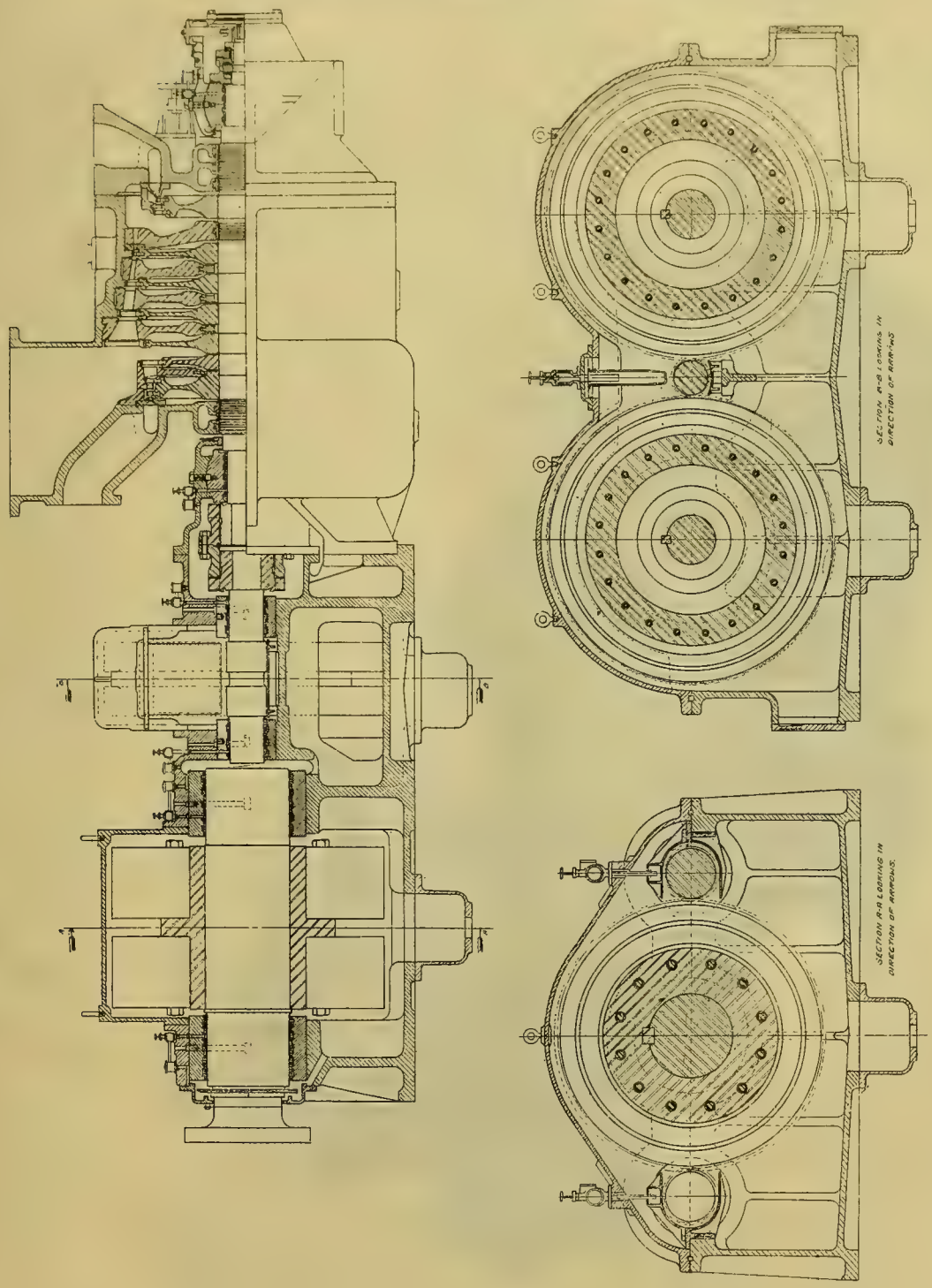
THE NORRIS PETERS CO., WASHINGTON, D. C.

To illustrate paper on "Alquist Gearing for Ship Propulsion," by W. L. R. Emmet, Esq., Member of Council.



2400 HP TURBINE WITH ONE PLANE ALL FLEXIBLE GEAR REDUCTION
FOR SHIP PROPULSION 3500/90 R. P. M.

To illustrate paper on "Alquist Gearing for Ship Propulsion," by W. L. R. Emmet, Esq., Member of Council.



ASSEMBLY OF CURTIS GEARED TURBINE, ONE PLANE TYPE FOR MARINE PROPULSION.

THE HARRIS PETERS CO., WASHINGTON, D.C.

To illustrate paper on "Alquist Gearing for Ship Propulsion," by W. L. R. Emmet, Esq., Member of Council.

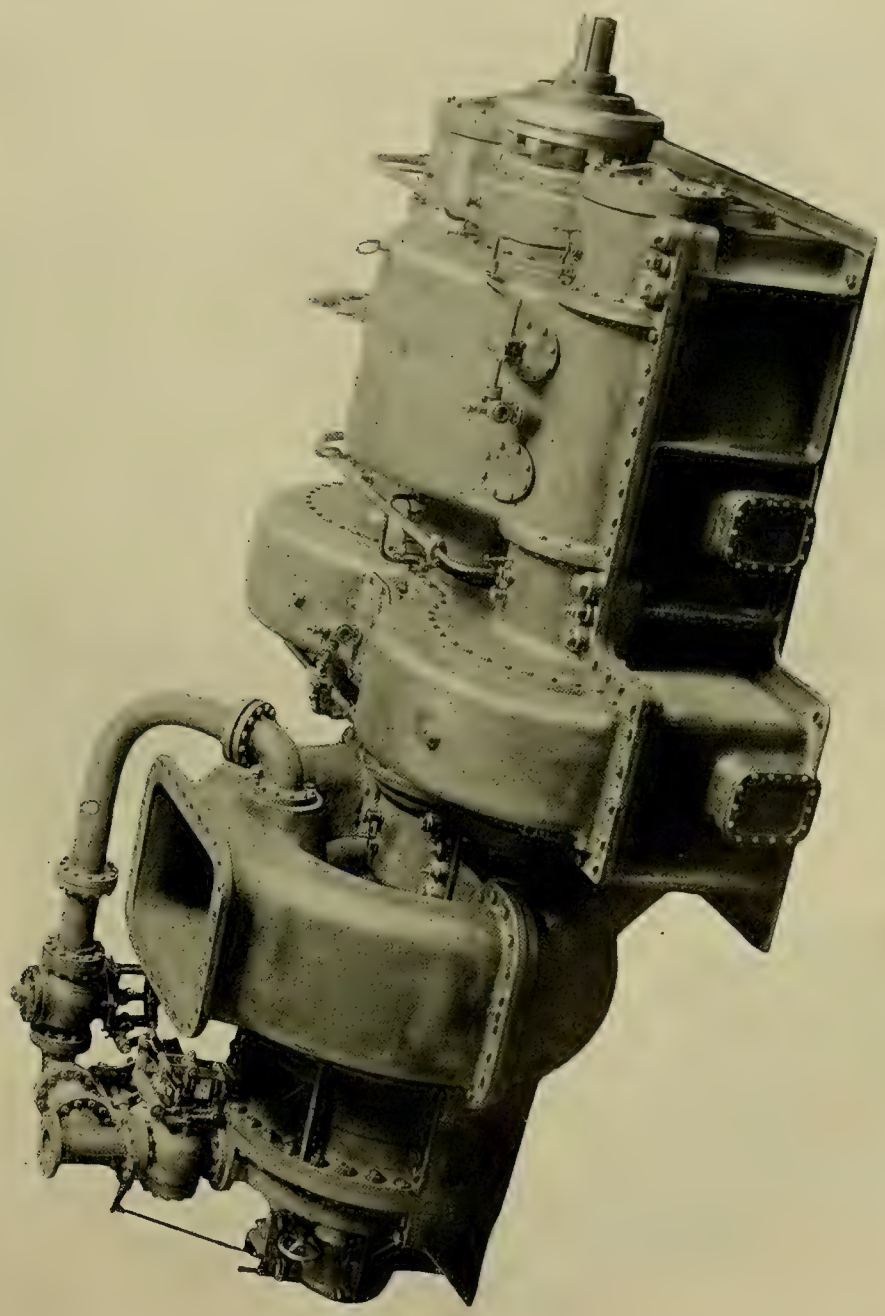


Fig. 6.—Curtis Turbine and One Plane Flexible Type Speed Reduction Gear for Ship Propulsion.

To illustrate paper on "Alquist Gearing for Ship Propulsion," by W. L. R. Emmet, Esq., Member of Council.

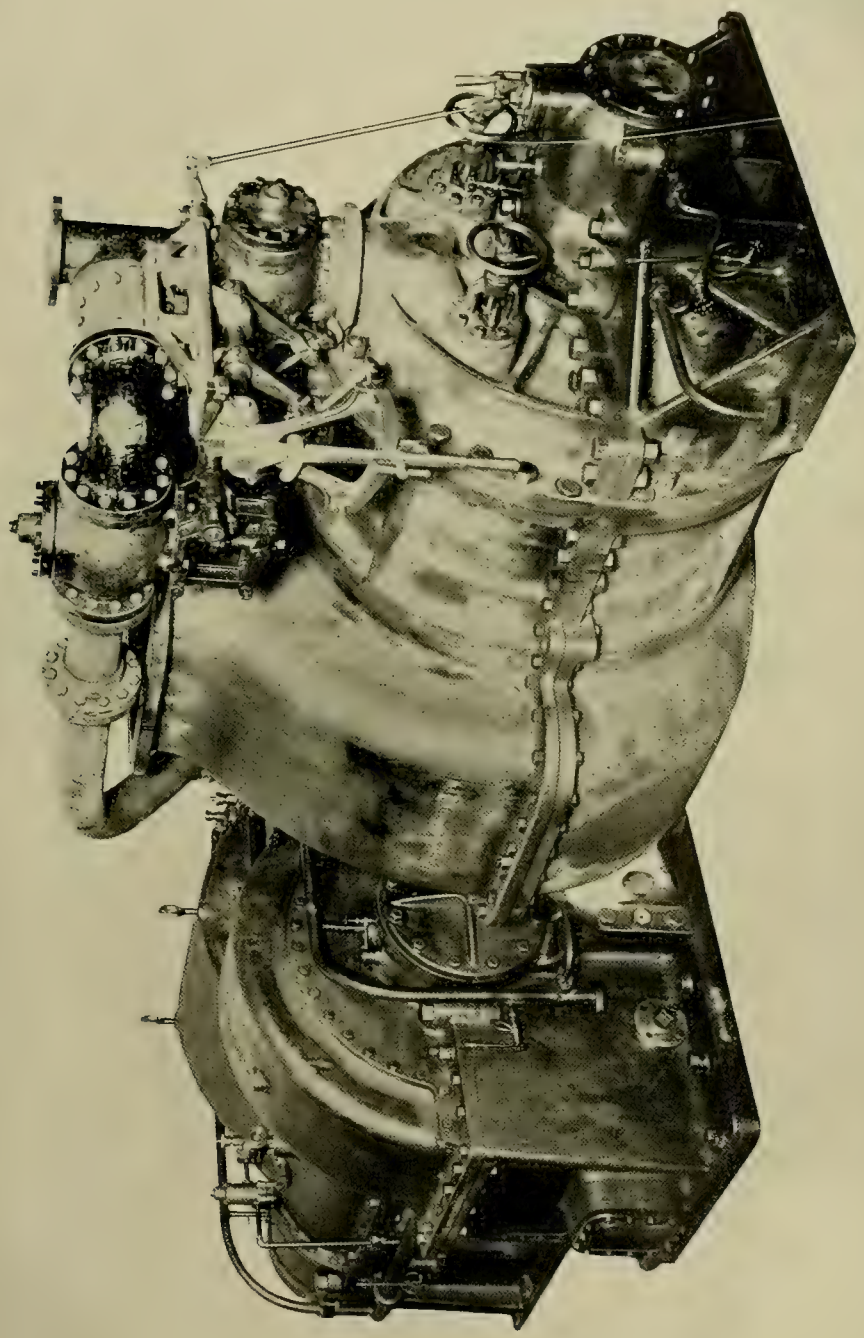


Fig. 7.—Curtis Turbine and One Plane Flexible Type Speed Reduction Gear for Ship Propulsion Showing Control.

To illustrate paper on "Alquist Gearing for Ship Propulsion," by W. L. R. Emmet, Esq., Member of Council.

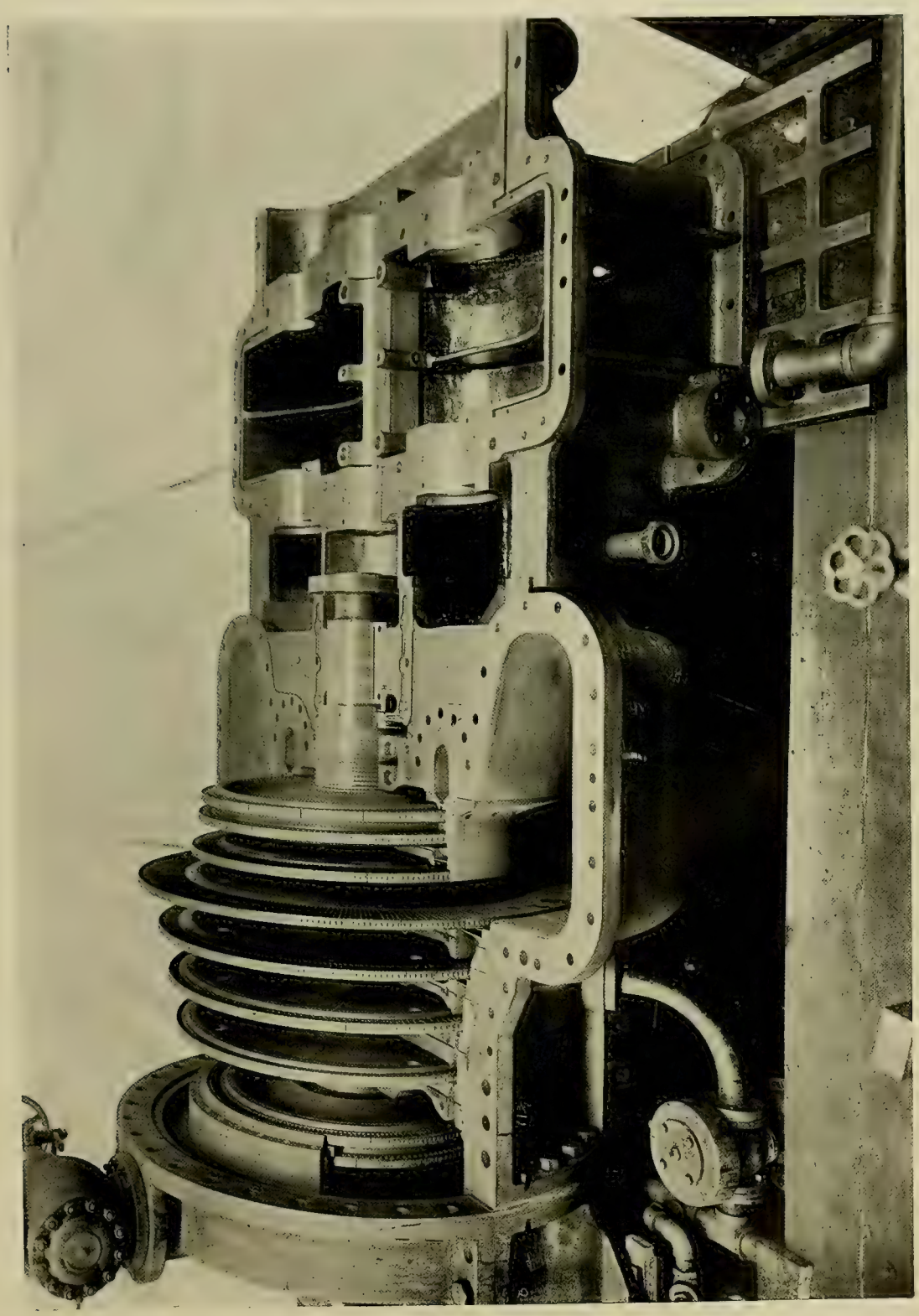


Fig. 8.—Wheels, Diaphragms and High Speed Gear Casing 2,400 H. P. 3,500/90 R. P. M. Reduction Gear Turbine Set for Ship Propulsion. Union Iron Works, San Francisco, Cal.

To illustrate paper on "Alquist Gearing for Ship Propulsion," by W. L. R. Emmet, Esq., Member of Council.

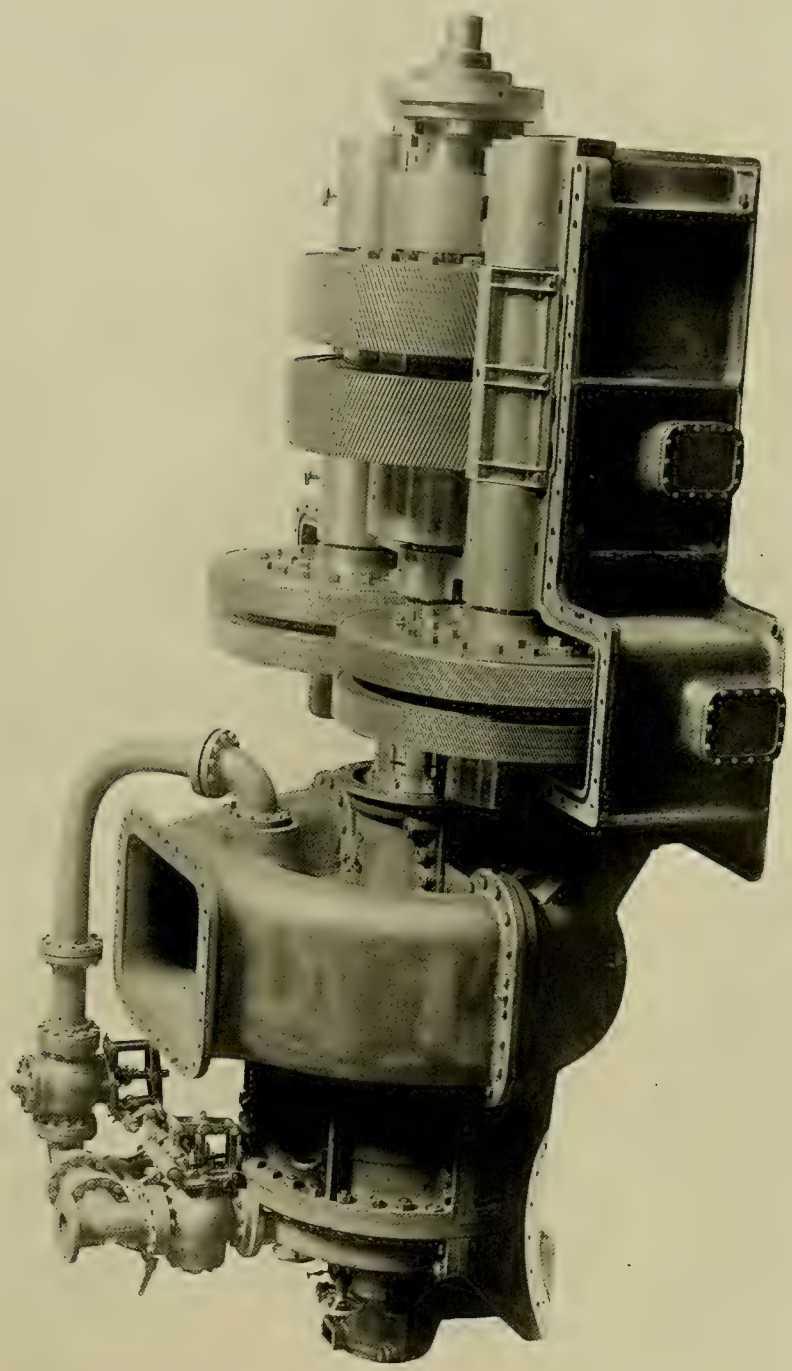


Fig. 9.—Curtis Turbine and One Plane Flexible Type Speed Reduction Gear for Ship Propulsion. Top Half of Gear Housing Removed.

To illustrate paper on "Electric Pumping Equipment and Notes of Interest on Union Oil Company of California's Tank Steamer La Brea," by Hugo P. Frear, Esq., Member.

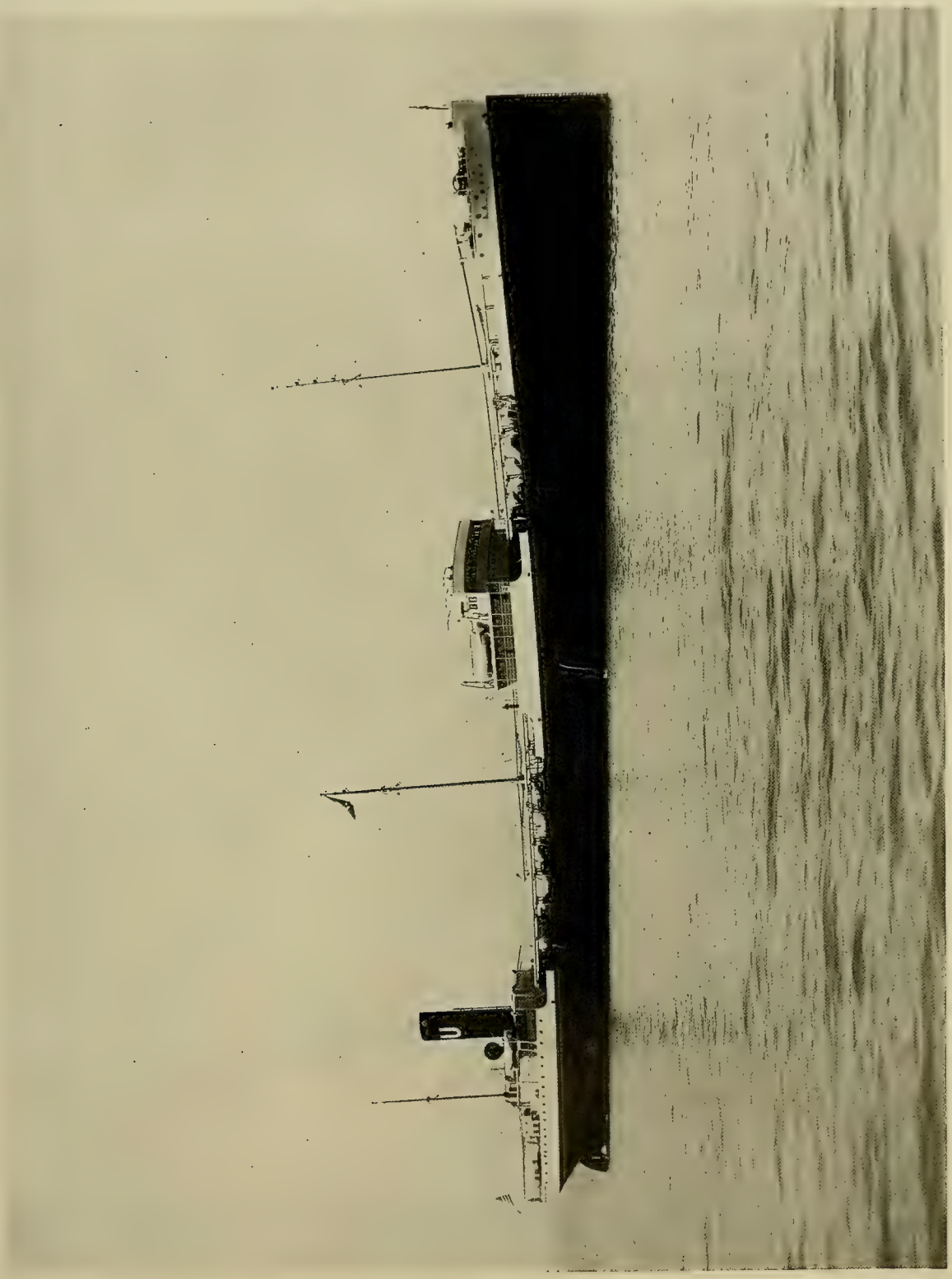
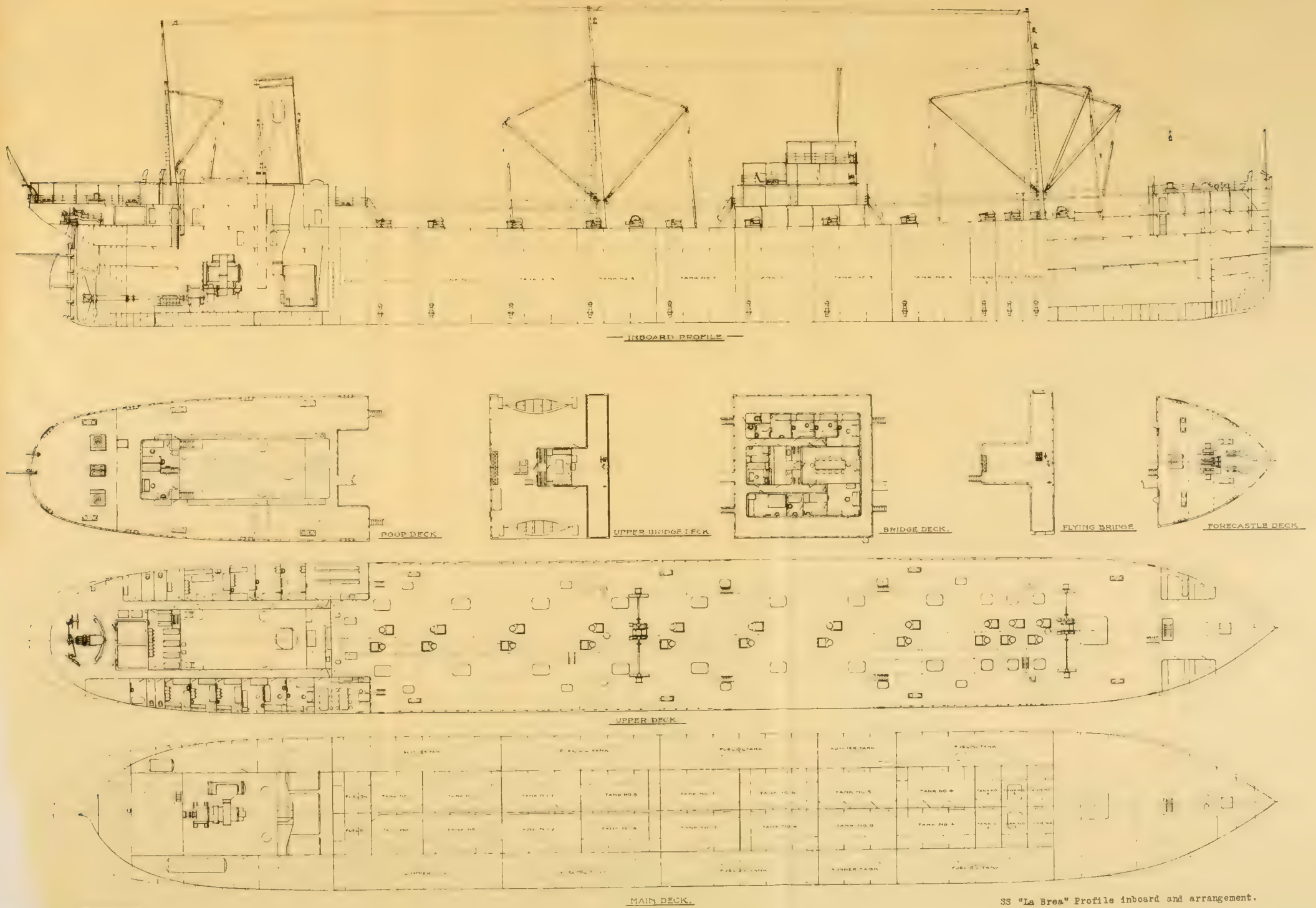


Fig. 1.—S.S. La Brea in Ballast Trim.

To illustrate paper on "Electric Pumping Equipment and Notes of Interest on Union Oil Company of California's Tank Steamer La Brea," by Hugo P. Frear, Esq., Member.



SS "La Brea" Profile inboard and arrangement.

To illustrate paper on "Electric Pumping Equipment and Notes of Interest on Union Oil Company of California's Tank Steamer La Brea," by Hugo P. Frear, Esq., Member.

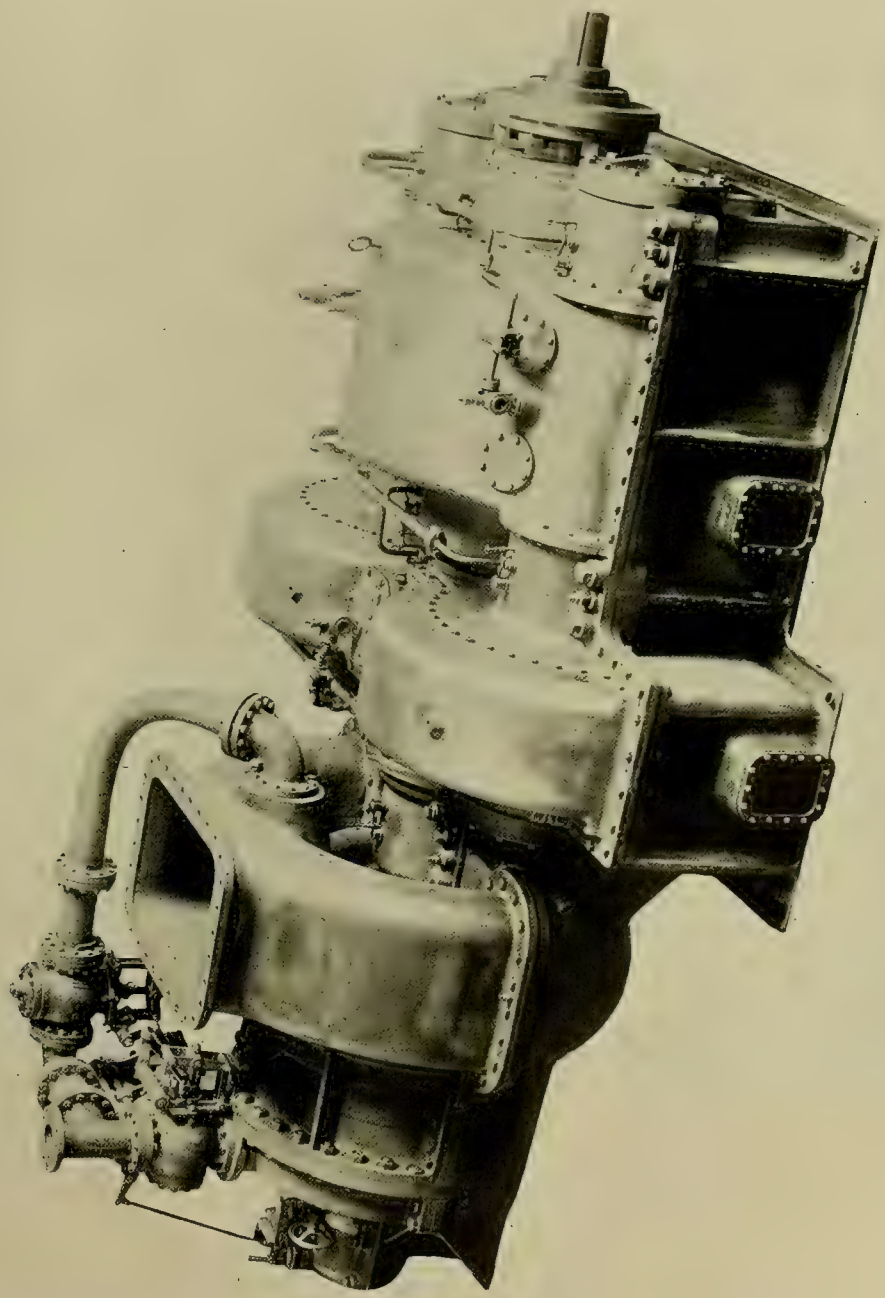


Fig. 3.—Assembled Reduction Gear—Turbine 2,600 S. H. P.

To illustrate paper on "Electric Pumping Equipment and Notes of Interest on Union Oil Company of California's Tank Steamer La Brea," by Hugo P. Frear, Esq., Member.

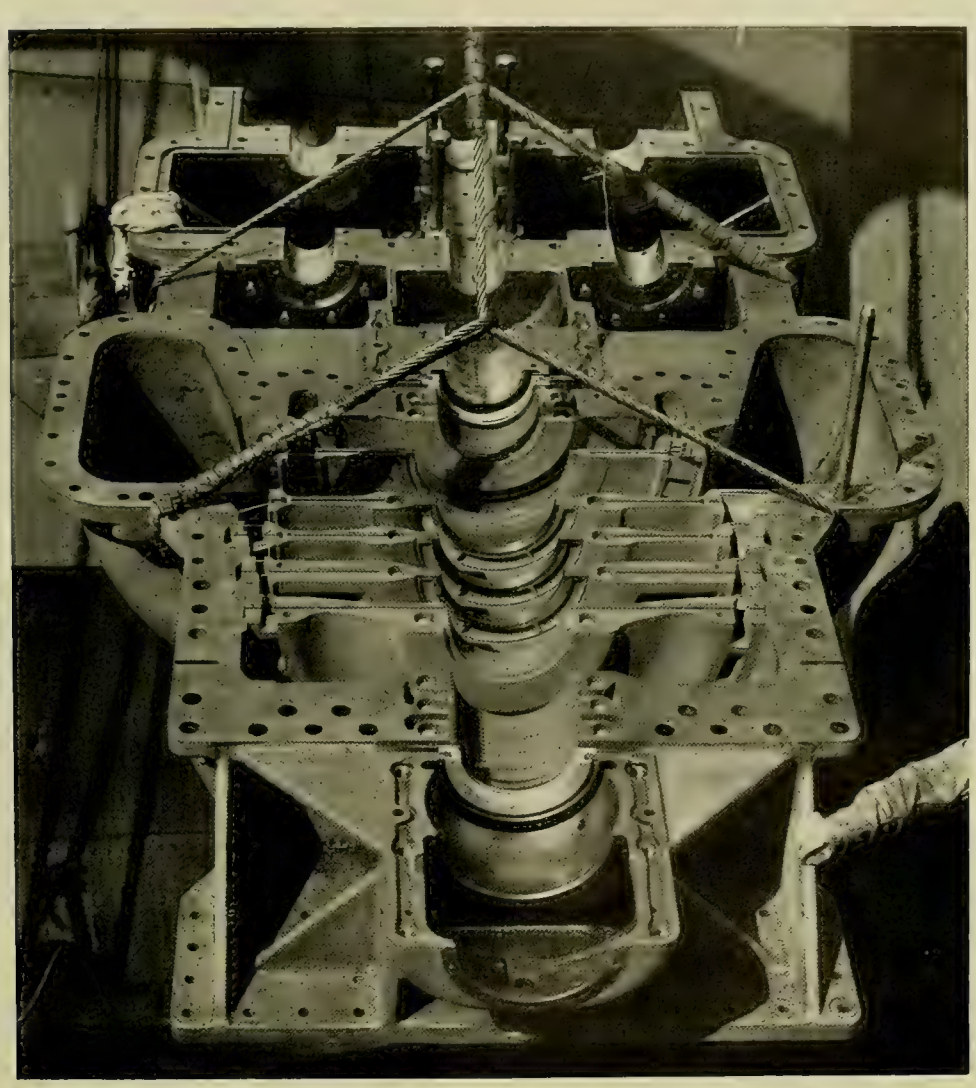


Fig. 4.—Lower Half of Turbine Casing for 2,600 S. H. P. G. E. Curtis Geared Turbine.

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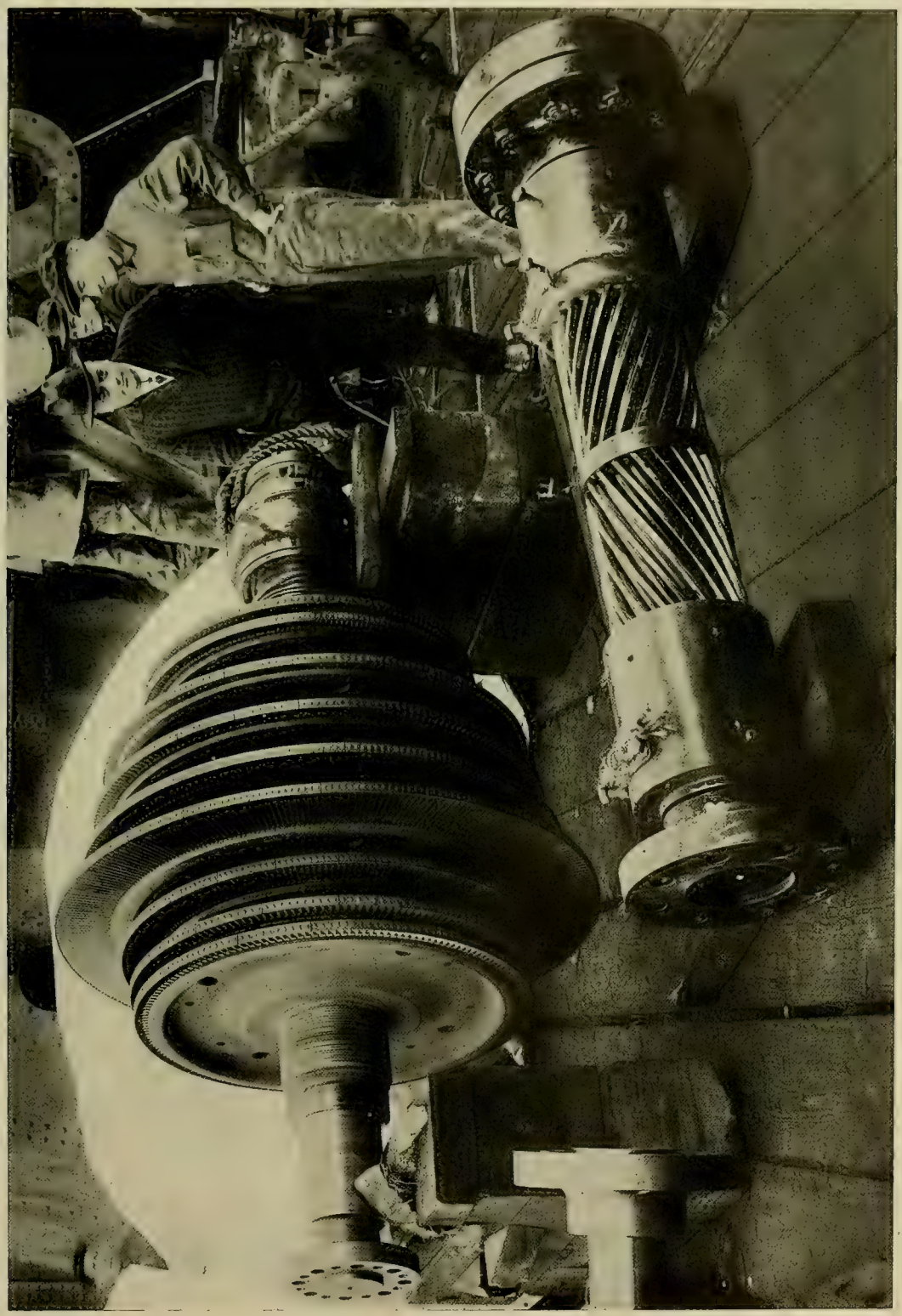

Fig. 5.—Rotor and Slow Speed Pinion for 2,600 S. H. P. G. E. Curtis Geared Turbine.

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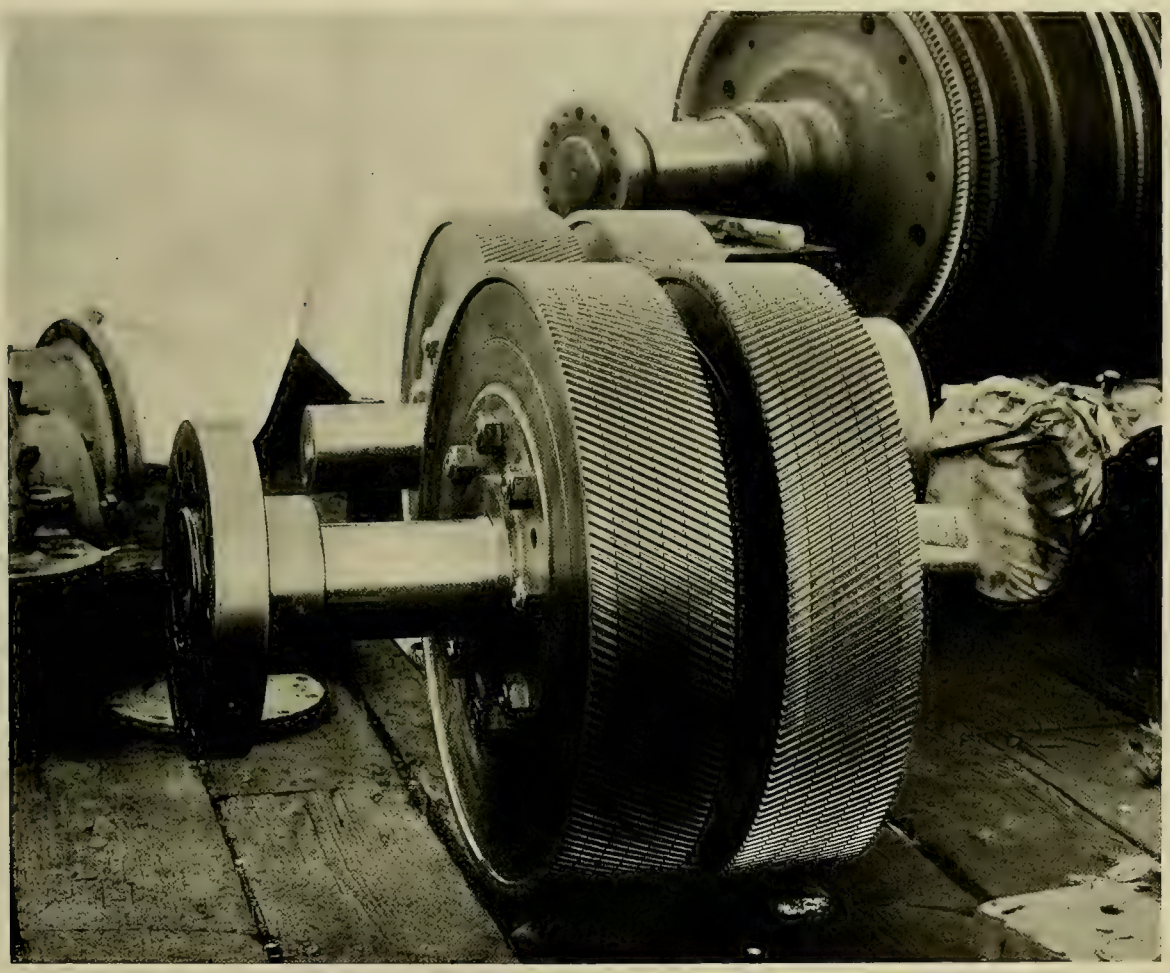

Fig. 6.—Intermediate Gears for 2,600 S. H. P. G. E. Curtis Geared Turbine.

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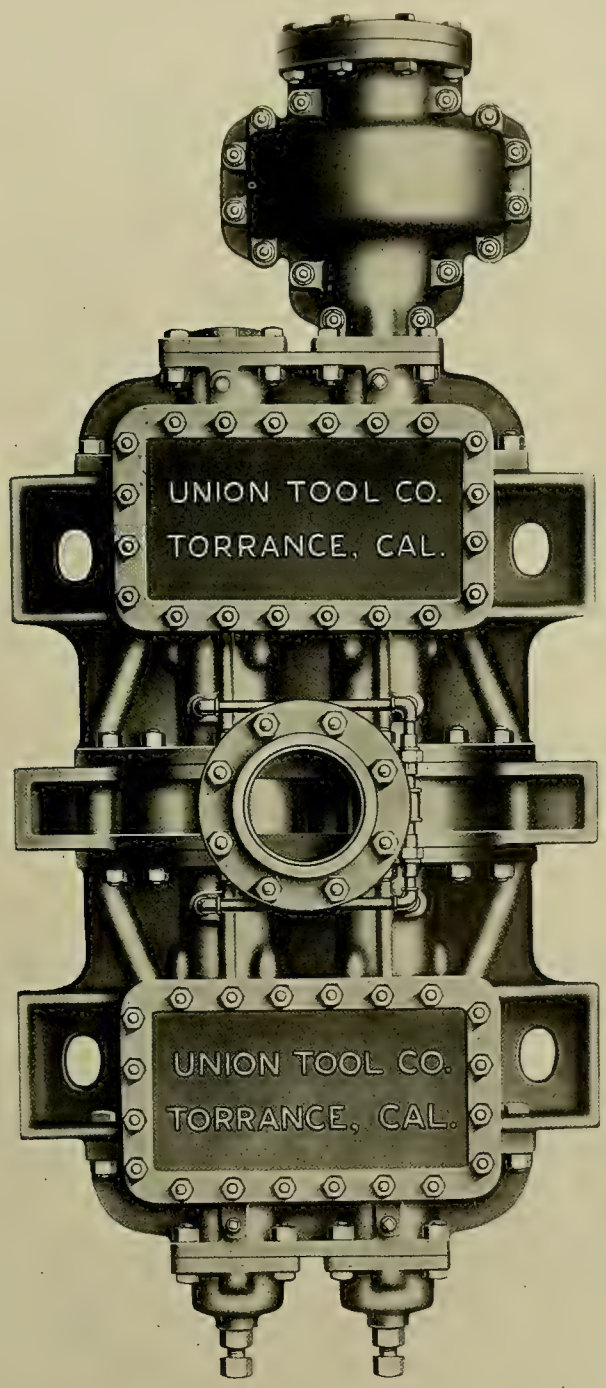

Fig. 7.—4″ Ideal Rotary Pump—External View.

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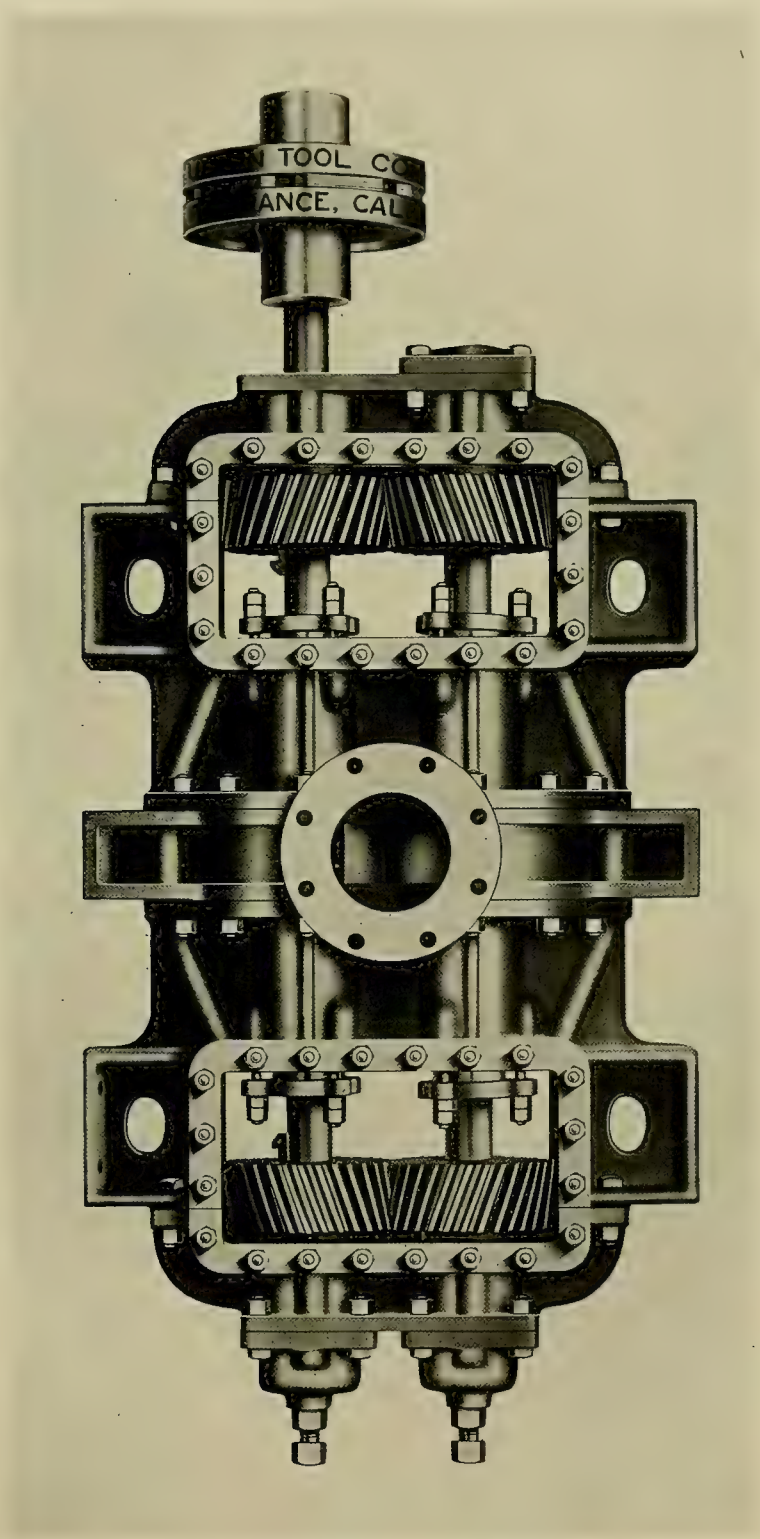

Fig. 8.—4" Ideal Rotary Pump with Gears Exposed.

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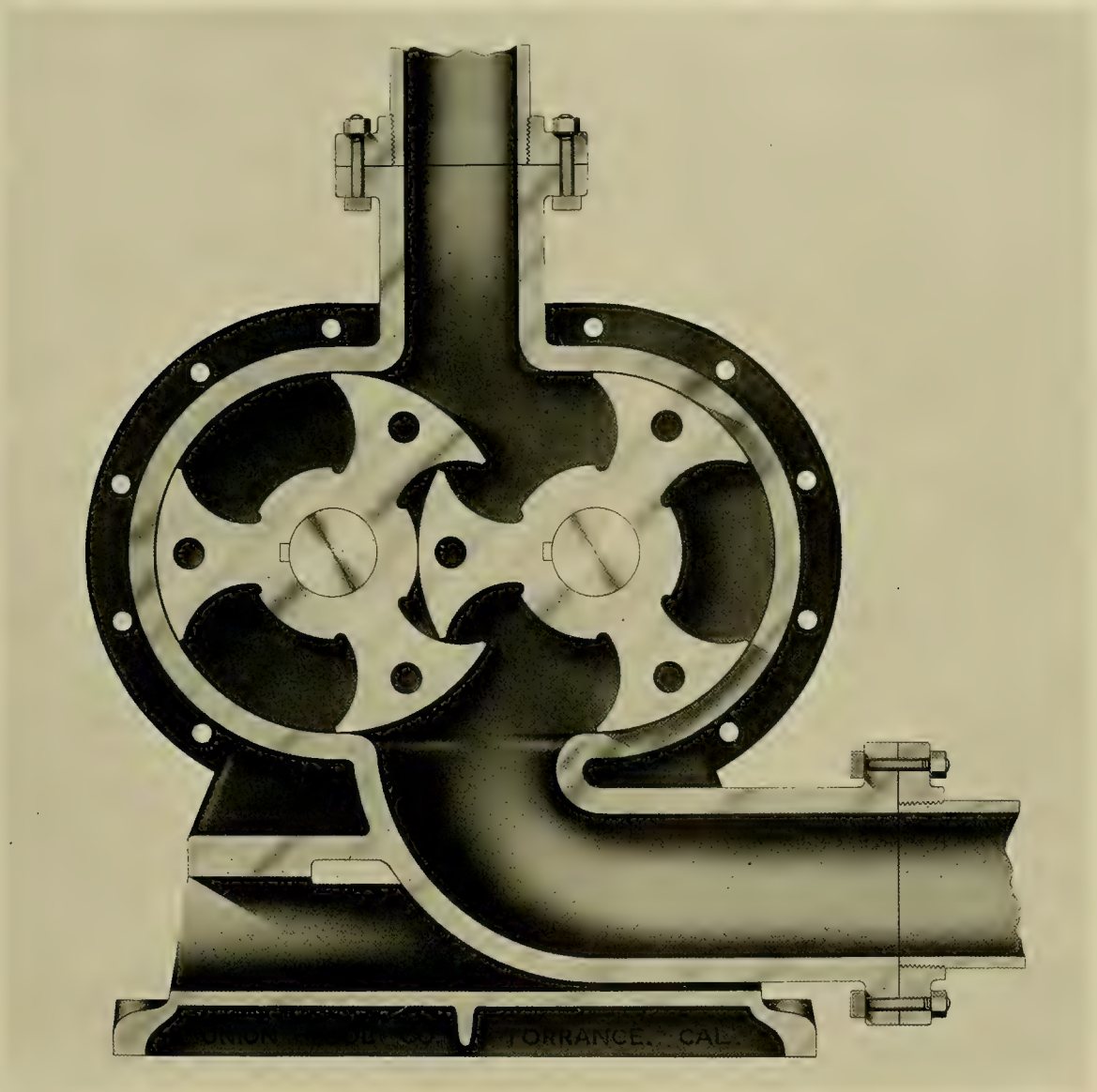

Fig. 9.—4″ Ideal Rotary Pump Rotars.

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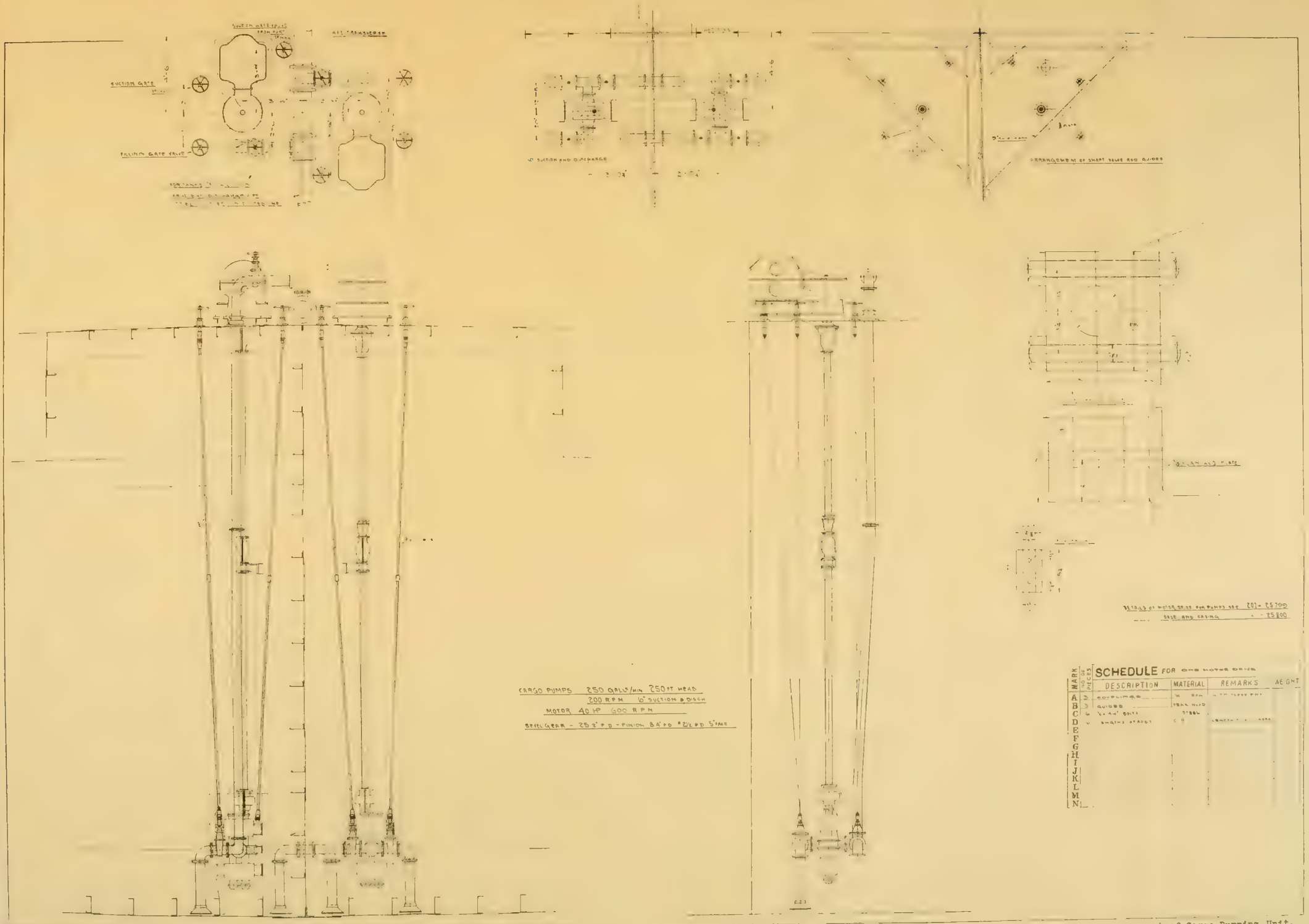

Arrangement of Cargo Pumping Unit.

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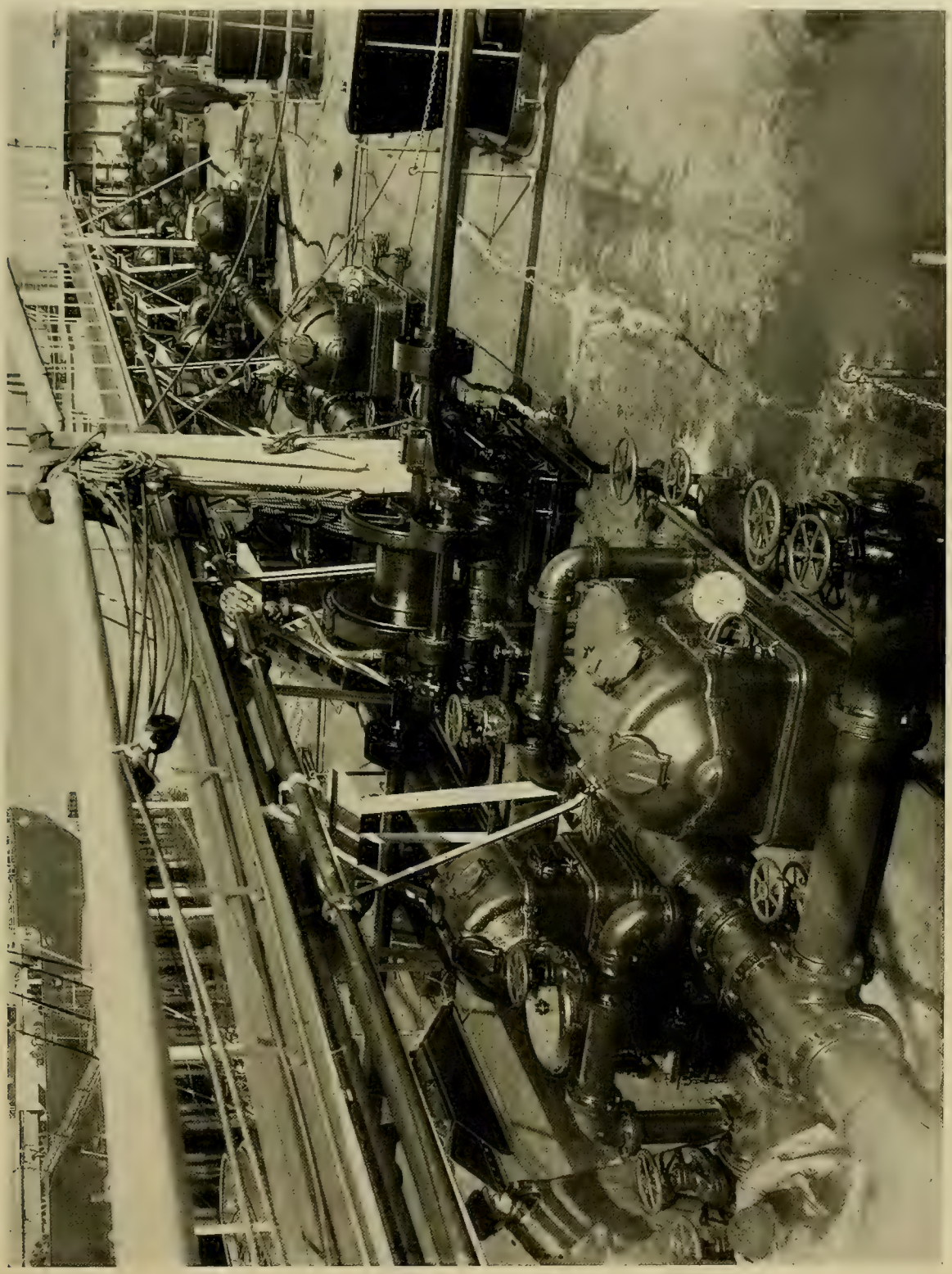

Fig. 11.—Pump Motor Installation.

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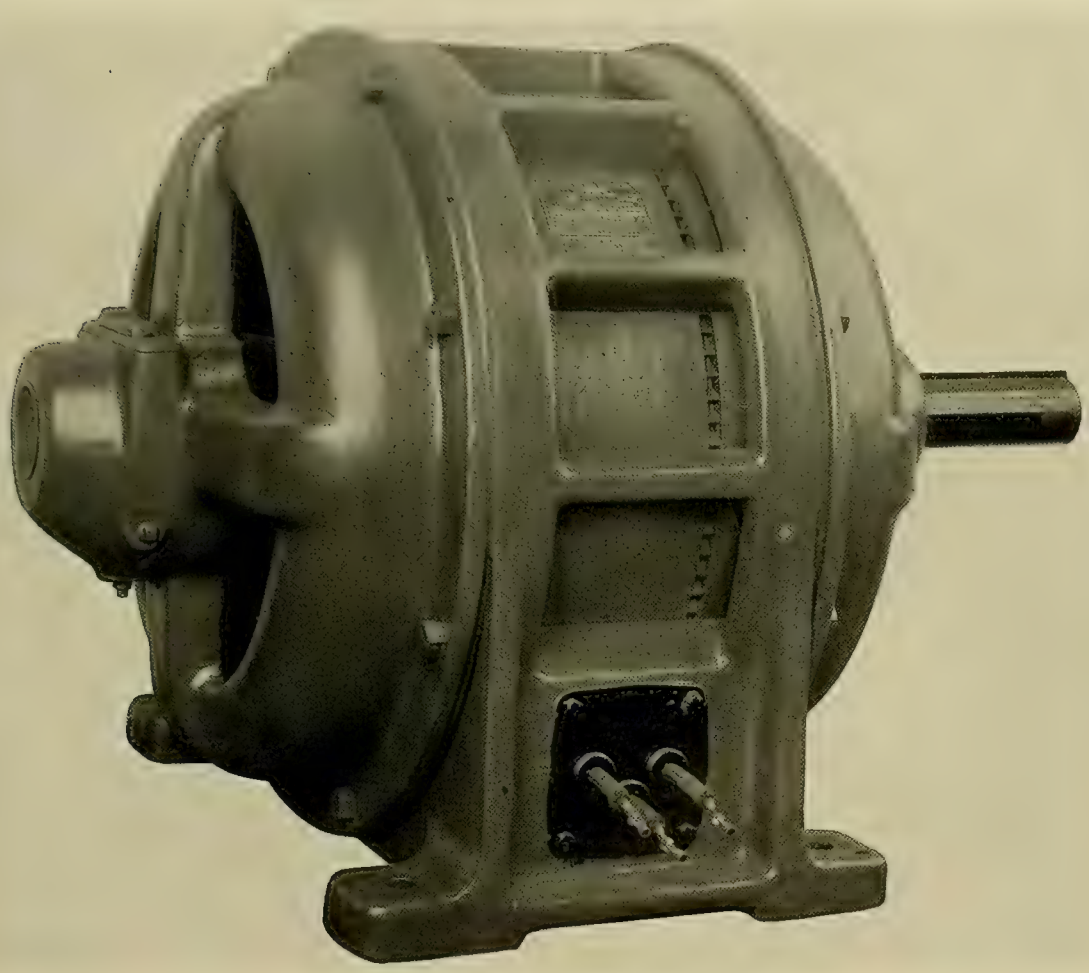

Fig. 12.—Squirrel Cage Open Type Motor.

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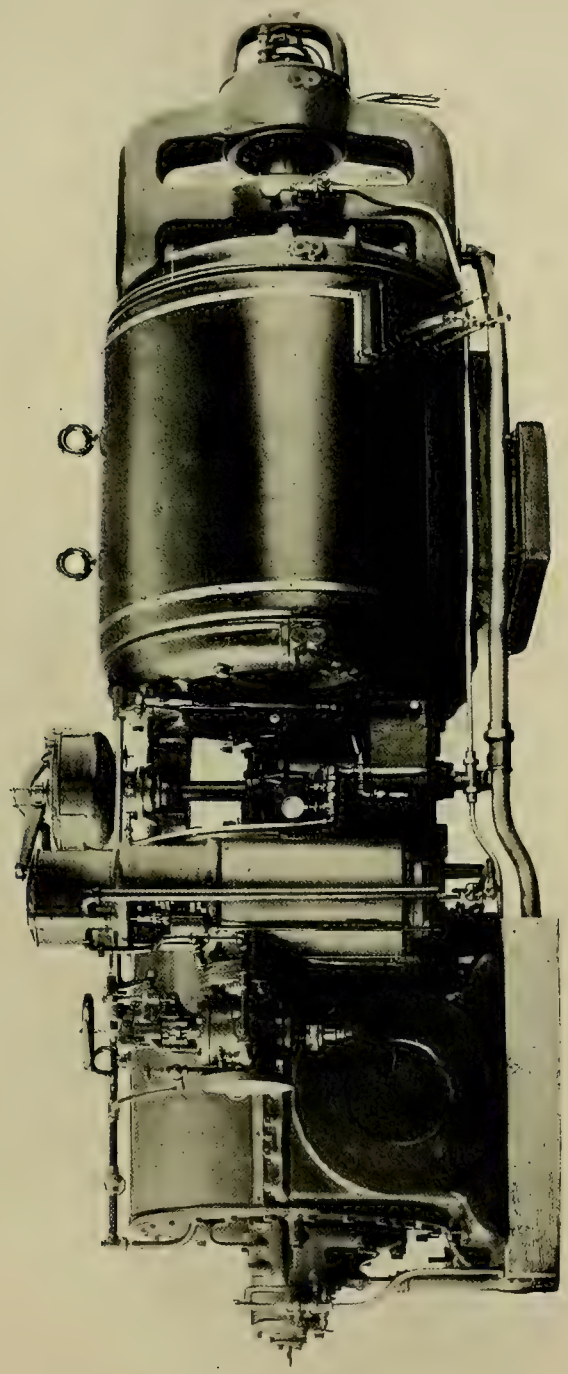

Fig. 13.—Turbo Generating Set.

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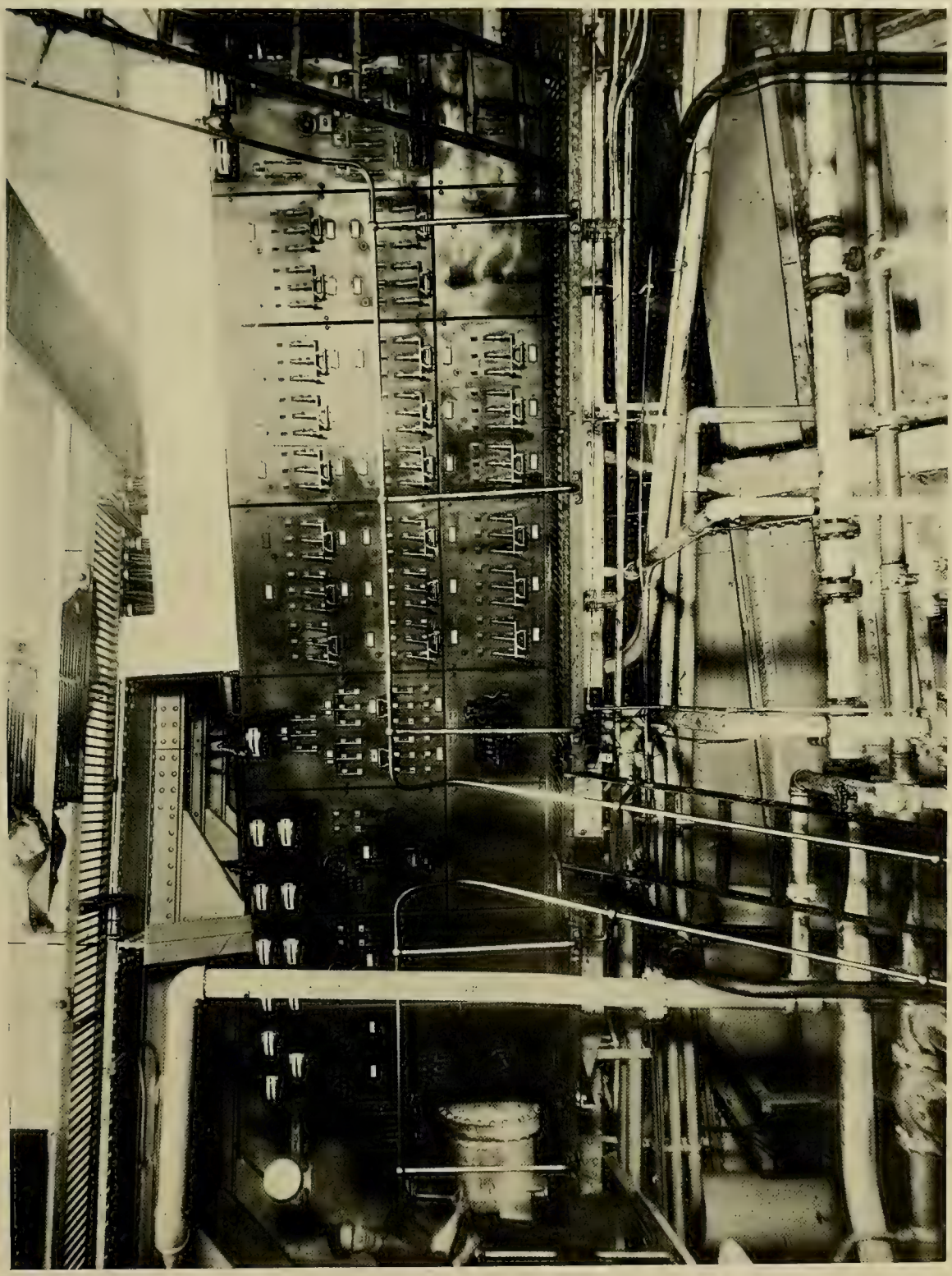

FIG. 14.—SWITCHBOARD.

To illustrate paper on "The Commercial Gyroscopic Compass," by Elmer A. Sperry, Esq., Member.

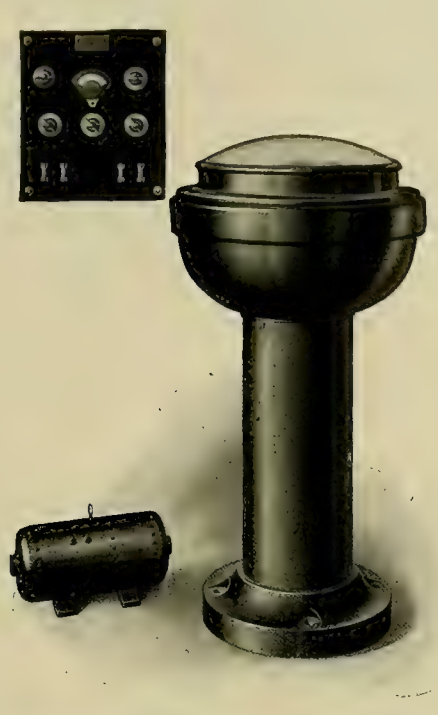

Fig. 1.—Commercial Compass, Simplest Form.

Fig. 2.—Full Equipment with Repeaters, Pelorus, Double Motor-Generator, and Battery.

To illustrate paper on "The Commercial Gyroscopic Compass," by Elmer A. Sperry, Esq., Member.

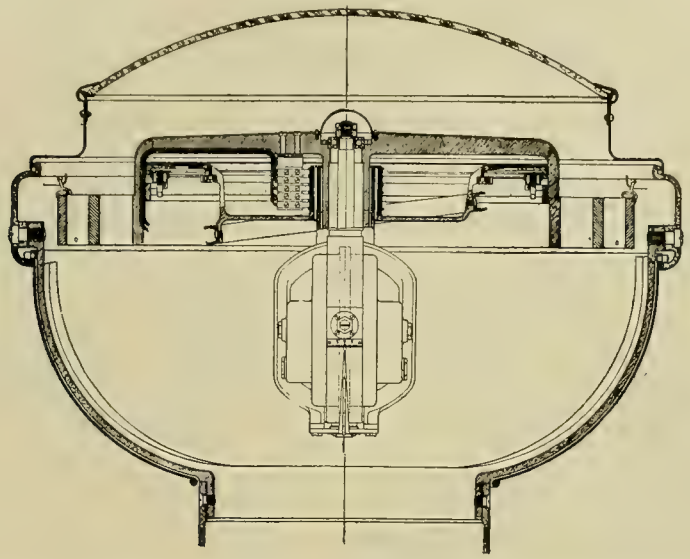

Fig. 3.—Sectional View of Binnacle and Portion of Compass Showing Internal Arrangement and Glass Cover.

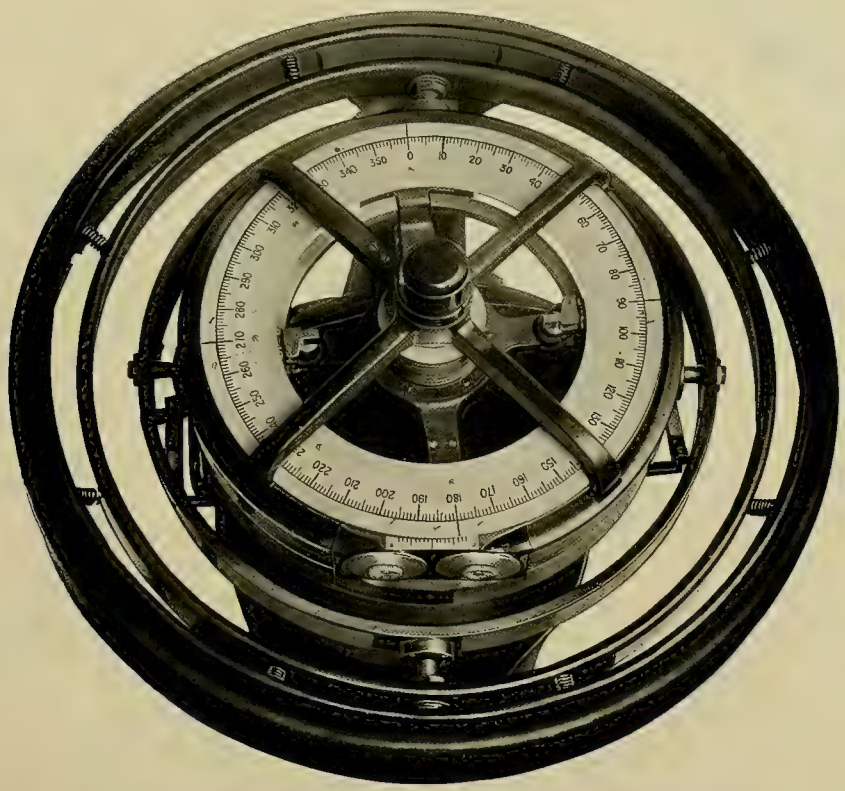

Fig. 4.—The Navy Type of Gyro-Compass Card, Showing Binnacle.

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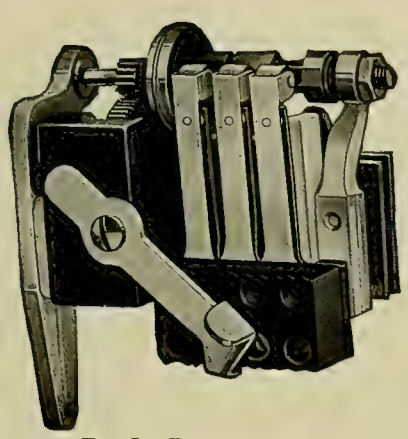

Fig. 5.—Transmitter.

Fig. 6.—Portable Repeater for Submerged Torpedo Fire.

Fig. 7.—Small Type Repeating Compass Mounted on Gimbal Ring.

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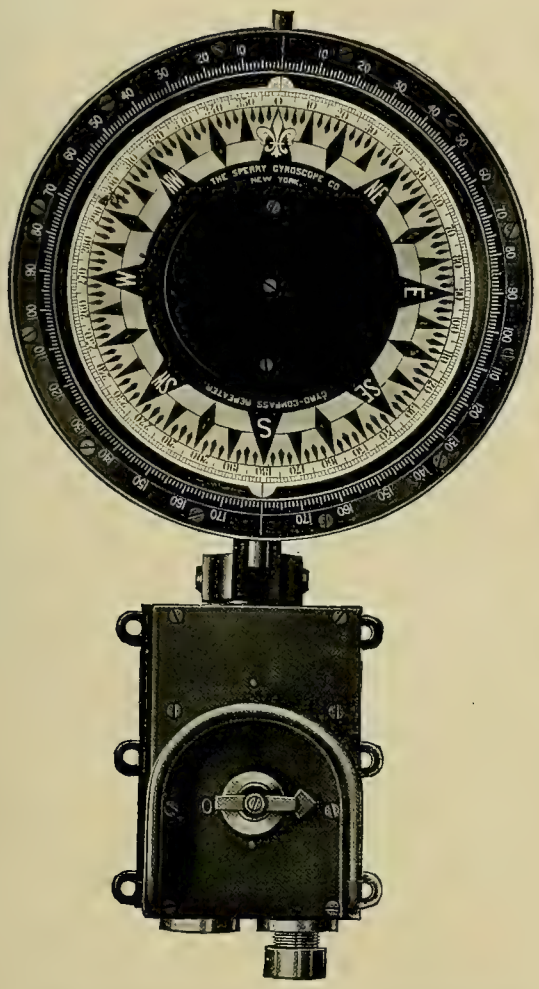

Fig. 8.—Eight-inch Repeater with Mounting and Dimmer.

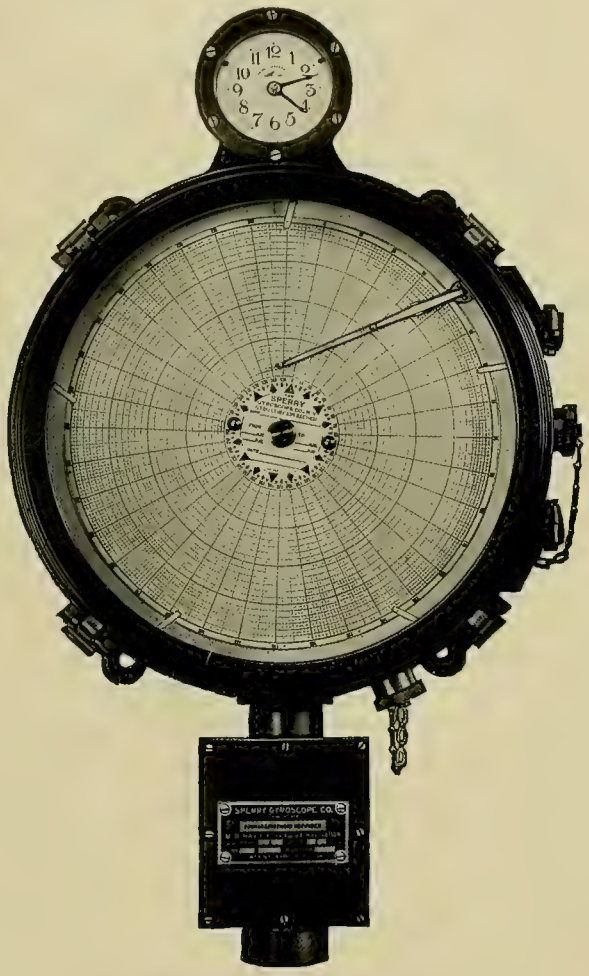

Fig. 9.—Recording Compass.

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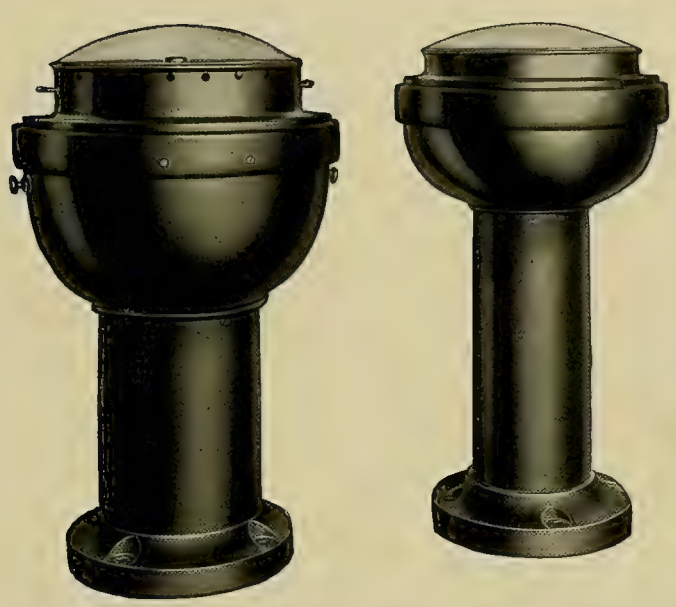

Fig. 10.—Comparison between Battle Compass and Commercial Compass.

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